

Physical Properties and Leach Testing of
Solidified/Stabilized Flue Gas Cleaning Wastes

(U.S.) Army Engineer Waterways Experiment
Station, Vicksburg, MS

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Jul 81



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PHYSICAL PROPERTIES AND LEACH TESTING OF
SOLIDIFIED/STABILIZED FLUE GAS CLEANING WASTES

by

Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
Vicksburg, MS 39180

Interagency Agreement No. EPA-IAG-D4-0569

Project Officer

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Results of testing to determine the physical properties and chemical leaching characteristics of five different flue gas cleaning (FGC) sludges and the stabilized/solidified products from five commercially available treatment processes are reported. This study suggests that solidification/stabilization of FGC wastes may be a feasible method of reducing their pollutant potential in landfilling. However, a great deal more study is necessary before the behavior of treated FGC sludges under actual field conditions can be adequately understood.

KEYWORDS: *Solid waste disposal, *Sludge disposal.

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report presents results from small-scale laboratory testing to determine the physical properties and chemical leaching characteristics of untreated and chemically solidified or stabilized flue gas cleaning (FGC) wastes. It provides basic data that can aid in estimating the potential for surface and groundwater pollution from FGC disposal activities and estimates of the strength and durability of the treated materials. Studies such as these provide the basis for decisions regarding disposal or productive uses of these rapidly accumulating waste materials and play a vital role in our efforts for energy independence.

FRANCIS T. MAYO
Director, Municipal Environmental
Research Laboratory

ABSTRACT

Results of testing to determine the physical properties and chemical leaching characteristics of five different flue gas cleaning (FGC) sludges and the stabilized/solidified products from five commercially available treatment processes are reported. This study suggests that solidification/stabilization of FGC wastes may be a feasible method of reducing their pollutant potential in landfilling. However, a great deal more study is necessary before the behavior of treated FGC sludges under actual field conditions can be adequately understood.

The treated sludges resembled soil-cement mixtures or low-strength concrete. No process produced consistent changes in specific gravity (lower void ratios) or water contents of the sludges; only two of the processes produced appreciable decreases in the permeability of the sludges; and only three processes had appreciably increased the compressive strengths of the wastes. The durability of the solidified sludges was low. The ability of treated wastes to contain potential pollutants cannot be adequately predicted simply using standard physical and engineering tests.

The major pollution problem associated with the untreated FGC sludges is that the leachate from the lime and limestone process sludges is saturated with respect to calcium sulfate (gypsum) and would be expected to remain so for long periods of time. The double alkali process sludges present an added initial problem of extremely high sulfate losses. Other contaminants found to exceed drinking water standards consistently in leachates from all untreated FGC sludges were arsenic, chromium, and manganese; while cadmium and lead exceeded drinking water standards only in relatively few leachate samples.

Leaching column tests indicated that the average concentrations of many of the constituents in the leachates collected over the duration of this study is reduced by most of the sludge treatment processes; however, no treatment process uniformly reduced the concentration of all potential pollutants in the leachate for all the types of sludges tested. Solidification/stabilization does tend to lower the pollutant potential of FGC sludges to surrounding waters. Reduction of the highest concentrations of sludge constituents occurring in the leachate was the most pronounced effect of sludge treatment. When the proportion of dry sludge solids contained in the final, solidified/stabilized product is considered, the beneficial effect of sludge treatment is less apparent. In some cases, additional leachable materials were apparently added to during treatment so that losses of some potential pollutants actually exceeded the amount of the constituent present in the original FGC sludge processed. Some treatment processes apparently increased the solubility of certain constituents so that these materials were lost from the treated sludge at higher rates than from the untreated.

The small sample size (with larger surface/volume ratio), and continuous submersion in a CO₂-saturated leaching solution as used in this study, appears to be a rigorous leaching condition. Most landfilling operations would allow the use of much larger masses of treated sludge (with smaller surface area/volume ratios) and saturated conditions would occur only intermittently. Thus conditions in an actual landfill should allow more effective containment of wastes than found in this study.

CONTENTS

Foreword	111
Abstract	iv
Figures	vii
Tables	ix
Acknowledgments	xii
1. Introduction	1
2. Conclusions	4
3. Recommendations	6
4. Materials and Methods	7
Sources, selection, and description of sludges	7
Selection of sludge processors	9
Stabilization techniques	9
Leaching column design	14
Chemical analysis	16
5. Physical and Engineering Properties of Treated and Untreated FCC Wastes	25
Background	25
Physical property tests and results	25
Engineering properties tests and results	35
Summary of physical and engineering properties	41
6. Results of Leach Testing	44
Patterns of sludge constituent leaching	44
Untreated FCC sludge composition	54
Constituent loss from untreated sludge columns	56
Constituent loss from treated sludge columns	62
Summary of chemical leaching data	79
7. Discussion	84
General comments	84
Solidification performance	84
Leach testing procedures	85
References	86
Appendices	
A. Results from non-priority leaching columns	88
B. Priority column loading and total amounts leached	99
C. Data set for priority leaching columns	105

FIGURES

<u>Number</u>		<u>Page</u>
1	Leaching column design and detail	11
2	Sample leaching columns in place in racks	15
3	Untreated (raw) and solidified FCC wastes from a lime process scrubber, eastern coal (No. 100)	17
4	Untreated (raw) and solidified FCC wastes from a limestone process scrubber, eastern coal (No. 400)	18
5	Untreated (raw) and solidified FCC wastes from a double alkali process scrubber, eastern coal (No. 500)	19
6	Untreated (raw) and solidified FCC wastes from a lime process scrubber, western coal (No. 600)	20
7	Untreated (raw) and solidified FCC wastes from a double alkali process scrubber, western coal (No. 1000)	21
8	Grain-size distribution of untreated FCC sludge from lime process, eastern coal (No. 100)	27
9	Grain-size distribution of untreated FCC sludge from limestone process, eastern coal (No. 400)	28
10	Grain-size distribution of untreated FCC sludge from double alkali process, eastern coal (No. 500)	29
11	Grain-size distribution of untreated FCC sludge from lime process, western coal (No. 600)	30
12	Grain-size distribution of untreated FCC sludge from double alkali process, western coal (No. 1000)	31
13	Concentration of calcium in leachate from untreated sludge columns	46
14	Calcium concentrations in leachate from treated and untreated lime process, eastern coal sludge (No. 100) columns	47

<u>Number</u>		<u>Page</u>
15	Sulfate concentrations in leachate from treated and untreated lime process, eastern coal sludge (No. 100) columns	49
16	Chloride concentrations in leachate from treated and untreated lime process, eastern coal sludge (No. 100) columns	50
17	Accumulated mass of calcium leached from treated and untreated lime process, eastern coal (No. 100) columns as function of leaching time	51
18	Accumulated mass of calcium leached from treated and untreated lime process, eastern coal (No. 100) columns as a function of accumulated leachate volume	53
19	Plot of the ratio of the average concentration of each constituent in the leachate from treated columns to the average concentration of the corresponding constituent in the leachate from the untreated columns . .	80
20	Plot of the ratio of the highest concentration of each constituent in the leachate from treated columns to the highest concentration of the corresponding constituent in the leachate from untreated columns	81
21	Plot of the ratio of the median percent leached of each constituent in the leachate from treated columns to the median percent of the corresponding constituent in the leachate from the untreated columns	82

TABLES

<u>Number</u>		<u>Page</u>
1	Major Characteristics and Chemical Constituents of Flue Gas Cleaning Wastes Included in This Study	2
2	List of Sludges Treated and Process Code	7
3	Formulation and Column Loading for Flue Gas Cleaning Sludges (Priority Columns)	12
4	Methods of Preservation of Leachate Samples	22
5	Limits of Detection for Metals in Low and High Resolution Analytical Procedures	22
6	Methods of Analysis for Anions and Other Parameters and Their Limits of Detection	24
7	Test Schedule for Treated and Untreated FCC Sludges	25
8	Specific Gravities of Treated and Untreated FCC Sludges	32
9	Physical Properties of Treated FCC Sludges	34
10	Atterberg Limits of Untreated Sludges and Those Treated by Process B	35
11	Changes in Dry Unit Weight with Compaction and Optimum Water Content of Sludges Treated by Process B	36
12	Unconfined Compression Test Data	38
13	Permeability Data for Untreated FCC Sludges	39
14	Permeability Data for Treated FCC Sludges	40
15	Results of Freeze-Thaw and Wet-Dry Durability Testing of Treated Sludges	42
16	Analysis of Untreated Flue Gas Cleaning Sludges	55
17	Leachate Volumes Collected from Priority, Untreated Sludge Columns	57

<u>Number</u>		<u>Page</u>
18	Concentration of Selected Constituents in Leachate from the Priority, Untreated FGC Sludge Columns	59
19	Percent of Selected Constituents Leached from Priority, Untreated FGC Sludge Columns over Entire Study	61
20	Concentration of Selected Constituents in Leachate from Priority Columns Containing Sludges Treated by Process A	64
21	Average and Highest Individual Concentration of Constituents from All Priority Sludge Columns Treated by Process A as Compared to Untreated Control Columns	65
22	Percent of Selected Constituents Leached from Priority Leaching Columns Containing Sludge Treated by Process A Compared with Untreated Control Columns	66
23	Concentration of Selected Constituents in Leachate from Columns Containing Sludges Treated by Processor B	67
24	Average and Highest Individual Concentrations of Constituents from All Priority Sludge Columns Treated by Process B as Compared to Untreated Control Columns	69
25	Percent of Selected Constituents Leached from Priority Leaching Columns Containing Sludge Treated by Process B as Compared to Untreated Control Columns	70
26	Concentration of Selected Constituents in Leachate from Priority Columns Containing Sludges Treated by Process E	71
27	Average and Highest Individual Concentrations of Constituents in Leachate from All Priority Sludge Columns Treated by Process E, as Compared to Untreated Control Columns	72
28	Percent of Selected Constituents Leached from Priority Leaching Columns Containing Sludge Treated by Process E as Compared to Untreated Control Columns	73
29	Concentration of Selected Constituents in Leachate from Priority Columns Containing Sludges Treated by Process F	74
30	Percent of Selected Constituents Leached from Priority Leaching Columns Containing Sludge Treated by Process F Compared with Untreated Sludge Columns	75
31	Concentration of Selected Constituents in Leachate from Priority Columns Containing Sludges Treated by Process G	76

Number

Page

- 32 Average and Highest Individual Concentration of Constituents
 from All Priority Sludge Columns Treated by Process G as
 Compared to Untreated Control Columns 77
- 33 Percent of Selected Constituents Leached from Priority
 Leaching Columns Containing Sludge Treated by Process G
 Compared with Untreated Sludge Columns 78

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SECTION 1

INTRODUCTION

The disposal of waste by-products of the power generation industry is becoming increasingly difficult, expensive, and dangerous to the environment. Existing Federal air pollution control regulations and standards for new, stationary air pollution sources make it virtually impossible to operate a power generating plant using untreated coal (even of moderate sulfur content) without an efficient flue gas desulfurization (FGD) system. Current air pollution control standards for new installations limit SO_2 emission to 1.2 pounds per million BTU heat input (1). This is the sulfur $\bar{x}$ emission which can be expected from a furnace without flue gas cleaning (FGC) equipment which is burning 0.8-1 percent sulfur coal (2). Thus, only power plants using very low sulfur coal will be able to operate without FGC systems.

The majority of FGC systems now being installed or planned are "nonregenerative" systems. In these, the SO_2 in the stack gas is reacted with scrubbing materials to form insoluble calcium sulfite and calcium sulfate which is collected in the form of a sludge called a FGD sludge. The term, FGC sludge, usually refers to a mixture of fly ash, bottom ash, and FGD sludge (3). Estimates for new power plants burning commonly available grades of coal place the annual production of FGC sludges (50 percent solids) at 20 million tons (wet weight) in 1980, 80 million tons by 1990, and 155 million tons by 1998 (1).

The sludges used in this study are representative of the wastes produced by the three most prevalent FGD systems: the limestone sludge is produced with calcium carbonate as a scrubbing reagent, the lime sludge with calcium hydroxide, and the double or dual alkali sludge with sodium sulfite. The latter process, the dual alkali system, forms a soluble product, sodium bisulfite, which is reacted with lime in a separate system (causticiser) to form calcium sulfite which precipitates and sodium sulfite which is recycled to the scrubbing tower. The relative amounts of calcium sulfite and calcium sulfate in the FGD sludges are highly variable depending upon the amount of oxygen available during the scrubbing operation and how the sludge is handled and stored. The calcium sulfite in FGD sludges oxidizes in air to calcium sulfate at a rate dependent upon pH and temperature.

The sludges used in this study are FGC sludges containing variable amounts of FGD wastes and ash. The major characteristics and chemical composition of the sludges are given in Table 1. All are alkaline, inorganic sludges that are 20-30 percent denser than water, have less than 50 percent solids, and contain large amounts of calcium, iron, sulfate, and chloride. The most prevalent heavy metals are chromium, manganese, and zinc. Also present at potentially hazardous but highly variable levels are arsenic, beryllium, cadmium, copper, lead, and nickel. The major source of these trace

TABLE 1. MAJOR CHARACTERISTICS AND CHEMICAL CONSTITUENTS OF FLUE GAS CLEANING WASTES INCLUDED IN THIS STUDY.

Waste Description	Ident. No. this Study	1978 Production (wet tons)	% Solids	Density (kg/m ³)	Sludge Liquor pH	Constituents >10,000 mg/kg (dry)	Constituents 100-10,000 mg/kg (dry)	Constituents 1-100 mg/kg (dry)
Lime Process, Eastern Coal	100	1,160,000	36	1280	10.3	Ca, Fe, SO ₄ , Cl	Cr, Hg, Mn, Zn	As, Be, Cd, Cu, Pb, Ni
Limestone Process, Eastern Coal	400	1,440,000	36	1280	10.0	Ca, SO ₄ , Cl	Cr, Fe, Hg, Zn	As, Be, Cd, Cu, Pb, Mn, Ni
Double Alkali Process, Eastern Coal	500	850,000	44	1330	13.1	Ca, Fe, SO ₄ , Cl	Cr, Hg, Mn, Zn	As, Be, Cd, Cu, Pb, Ni
Lime Process, Western Coal	600	2,600,000	20	1120	7.5	Ca, Fe, SO ₄ , Cl	Cr, Hg, Mn, Zn	As, Be, Cd, Cu, Pb, Ni
Double Alkali Process, Western Coal	1000	600,000	39	1330	12.7	Ca, SO ₄ , Cl	Fe, Hg	Be, Cd, Cr, Cu, Pb, Mn, Ni, Zn

elements is the coal burned, but significant amounts can also come from the scrubbing materials and the makeup water. The nonvolatile elements such as chromium, manganese, and nickel, are retained in the fly ash and bottom ash so that their concentration in the sludge is dependent on the relative amounts of ash in the sludge. The highly volatile elements, such as arsenic, cadmium, fluorine, mercury, and selenium, are concentrated in the scrubber and enter the waste via the FGD sludge (4). Since coal is the principal minor element source and FGC sludge is produced at weights of 5-40 percent of the coal burned, the trace elements will be concentrated in the FGD sludge at 2 to 20 times their level in the coal. Further, the trace metals are present in the sludge largely as oxides which are more soluble and chemically reactive than their original form in the coal where they are typically found as sulfides or are bound in an organic matrix. Thus, these heavy metals form a potential hazard if allowed to be leached from the FGC sludge disposal sites and their containment is a basic consideration in this study.

The fine-grained nature of FGC sludges presents a serious problem in the handling, dewatering, transportation, and disposal of these wastes. The poor handling characteristics of FGC sludges result largely from the platelike or rosettelike form of the calcium sulfite crystals. A high proportion of these crystals in the sludge produces a thixotropic mixture with high moisture content and poor settling characteristics. The sulfite-rich FGC sludges are especially difficult to dewater and exhibit low compactibility. When confined to a mold, sludge samples exhibit fair resistance to compaction but this resistance disappears when the mold is removed.

The predominant method of disposing of these FGC sludges in the past has been by ponding (to dewater the sludge) which may be followed by burial in a landfill. Such disposal methods have a high potential for long-term loss of constituents into adjacent ground and surface waters (5, 6). A technology currently being developed and used to address this problem is that of chemical solidification and/or stabilization of the sludge. This treatment attempts to improve the waste's handling characteristics and decrease its potential to leach undesirable constituents. In this process, additives are combined with the wet sludge and allowed to react with the water and minerals in the sludge to form a solid mass or soillike material. Most stabilization processes decrease the permeability of the sludge and produce chemical conditions (increased pH) that lower the solubility of sludge constituents.

This study was established to assess the effectiveness of five different methods of treating FGC wastes in restricting the release of constituents to contacting waters. Five different FGC sludges were treated using commercially available sludge stabilization technology. The effect of solidification on several physical and engineering properties of the sludge was determined. The treated and untreated sludges were exposed to leaching conditions in specially designed columns for up to two years in a controlled environment and the resulting leachates analyzed chemically. The chemical leaching data are used to assess the effectiveness of the stabilization processes in containing waste constituents in the FGC sludge tests.

SECTION 2

CONCLUSIONS

Laboratory studies of the physical properties and chemical leaching characteristics of five different FGC sludges and the treated products from five commercially available stabilization/solidification processes have been completed. Data from these investigations can be used to evaluate potential pollution problems involved in standard landfill or land burial disposal of these wastes.

Extensive, standard physical and engineering tests indicated that the solidification processes did not always change the physical properties of the sludges in ways which would be expected to enhance their ability to contain their constituents. Although the final products resembled soil-cement mixtures or low-strength concrete, no process produced consistent changes in specific gravity (lower void ratios) or water contents of the sludges; only two of the processes produced appreciable decreases in the permeability of the sludges; and only three processes had appreciably increased the compressive strengths of the products. The durability of the final products was low; only one product survived 12 wet-dry cycle tests, and none completely survived 12 freeze-thaw cycles.

The loss of constituents in the leachate from the experimental columns typically followed one of two distinct patterns with or without treatment. Those constituents whose concentration in the sludge greatly exceeded their solubilities (e.g., calcium, nickel, lead, and sulfate) were found at relatively constant concentrations in the leachates over the course of the testing. For these constituents, the rate of loss is dependent upon the volume of leachate produced and independent of the length of time over which the leaching takes place. The second leaching pattern was seen in those constituents whose solubilities were large compared to their concentration in the sludge (e.g., chloride and nitrate). These constituents had very high concentrations in the initial leachate followed immediately by an asymptotic drop in concentration as the element was depleted from the sludge exposed to the leaching medium. Channelization of leachate flow in the untreated sludge columns greatly increased the rate at which the concentration of the soluble constituents in the leachate fell off as this process lessened the amount of sludge that came in contact with the leaching medium.

The major pollution problem associated with the untreated FGC sludges is that the leachate from the lime and limestone process is saturated with respect to calcium sulfate (gypsum) and would be expected to remain so for long periods of time. Typically this leachate contains 500-600 mg/l calcium and 1200-1500 mg/l sulfate. The double alkali process sludges present an added initial problem of extremely high sulfate losses (due presumably to relatively

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high proportion of sodium and/or potassium). Leachates containing 35,000 to 40,000 mg/l sulfate were found in early samples from all double alkali columns. Depletion of the monovalent cations from the double alkali sludges brings about a lowering of the sulfate levels to that found for leachate from other sludge types. Other contaminants found to exceed drinking water standards consistently in leachates from all untreated FGC sludges were arsenic, chromium, and manganese; while cadmium and lead exceeded drinking water standards only in relatively few leachate samples.

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Leaching column tests indicated that the average concentrations of many of the constituents in the leachates collected over the duration of this study are reduced by most of the sludge treatment processes; however, no treatment process uniformly reduced the concentration of all constituents in the leachate for all the types of FGC sludges tested. Solidification/stabilization does tend to lower the pollutant potential of FGC sludges to contacting waters. Reduction of the highest concentrations of sludge constituents occurring in the leachate was the most pronounced effect of sludge treatment. When the proportion of dry sludge solids contained in the final, solidification/stabilization product is taken into account, the apparent beneficial effect of sludge treatment is reduced. In some cases, additional leachable materials were apparently added during treatment so that losses of some constituents actually exceeded the amount of the constituent present in the original sludge processed. Some treatment processes increased the solubility of certain constituents so that they were lost at higher rates from the treated sludge than from the untreated (e.g., magnesium and sulfate).

The small sample size (with larger surface/volume ratio) and continuous submersion in a CO₂-saturated leaching solution as used in this study, appear to represent very vigorous leaching conditions. Most landfill operations would allow the use of much larger blocks of treated sludge (with smaller surface/volume ratios) and would have only intermittent saturating conditions occurring in the soil. Thus conditions in a landfill would favor the containment of the treated wastes.

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SECTION 3

RECOMMENDATIONS

The results of this study suggest that solidification/stabilization of FGC wastes may be a feasible method of reducing their pollutant potential in landfilling. However, a great deal more study is necessary before the behavior of treated FGC sludges under actual field conditions can be adequately understood.

Based on two years of leaching data, the physical and engineering properties thought to be important in assessing the effectiveness of solidification/stabilization techniques appear to be of only moderate predictive value. Specific testing procedures should be developed and standardized which have direct bearing on the ultimate behavior of the final product under actual landfill conditions. This can only be done after a sufficient understanding of the important variables affecting the loss of pollutants from similar treated materials under actual landfill conditions is gained.

Large-scale, controlled tests using treated sludge samples more nearly typical of the surface-to-volume relationship actually encountered in landfill situations are needed to give a more realistic estimate of treatment benefits. Intermittent saturation of the treated samples should also be considered in any future testing.

Calculation of solidification/stabilization benefits should be based upon the actual sludge solids incorporated into the treated sludge to separate the effects of simple dilution of the waste from those of stabilization.

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SECTION 4

MATERIALS AND METHODS

SOURCES, SELECTION, AND DESCRIPTION OF SLUDGES

The sludges used in this study represent typical types of sludges currently produced in FGC operations. These FGC sludges were obtained from five, coal-burning, electric-power plants. A listing of the sludges studied is included in Table 2 along with a numerical code used to identify each sludge type. The sludges examined were primarily calcium sulfate and sulfite sludges produced by the reaction of sulfur combustion products with calcium carbonate or hydroxide, directly or indirectly.

TABLE 2. LIST OF SLUDGES TREATED AND PROCESS CODE*

Flue Gas Cleaning Sludges	Sludge ID No.	Process Designation
Lime process, eastern coal	100	A, B, E, F, G
Limestone process, eastern coal	400	A, B, E, G
Double alkali process, eastern coal	500	A, B, E, G
Lime process, western coal	600	A, B, E, F, G
Double alkali process, western coal	1000	A, B, E, G

* Processes designated by code letter only (see text for generic description of the processes).

The FGC sludges, as a group, are quite consistent with regard to their chemical and physical properties. Constituents present in the greatest concentration in these sludges are calcium sulfite and sulfate, and sodium sulfite and sulfate; constituents typically present in lesser amounts include iron oxide, calcium carbonate, calcium hydroxide, and silicates. Most of the trace metal load in the sludge is derived from the coal that was burned rather than from the neutralizing agent used in the sulfur scrubbing (4).

FGC sludges result from the scrubbing of sulfur oxides

(SO_x) out of stack gasses. Their largest single source is electric-power plants. Sludges used in this study represent the three principal types of non-regenerative FGC sludges presently being produced in the United States: the lime, limestone, and double (or dual) alkali scrubbing systems. The lime and limestone systems account for over 90 percent of the scrubbing capacity from utility power plants, while double alkali systems currently dominate in the smaller, industrial, fossil fuel-fired steam generators. Projections through 1985 indicate that lime and limestone systems will continue to dominate the FGC field, but several large-scale double alkali systems are expected to go on line before 1990 (7).

The lime (Ca(OH)₂) FGC scrubbing process proceeds in two stages: (1) the absorption of SO₂ and CO₂ gasses by the basic lime solution, the subsequent hydration of the absorbed SO₂ to sulfite (SO₃) with variable amounts of the oxidation of the sulfite to sulfate (SO₄), and (2) the reaction of the anions with the dissolved calcium to form the relatively insoluble products, calcium sulfite hemihydrate, calcium sulfate dihydrate, and calcium carbonate. These precipitates, mixed with unreacted lime and particulates removed from flue gas, make up the FGC sludge. The pH of the scrubbing slurry ranges between 7 and 11, depending on the proportion of the unreacted slurry recycled. Reaction kinetics at this pH favor the production of the calcium sulfite hemihydrate, rather than calcium sulfate dihydrate.

The limestone (CaCO₃) FGC scrubbing can also be summarized as a two-step process: (1) the absorption of the SO_x reaction products in the gas by the calcium carbonate slurry and their subsequent hydration to sulfite ions and possible oxidation to sulfate ion, and (2) the reaction of these ions with dissolved calcium to form calcium sulfite and calcium sulfate. Much of the carbonate is lost as carbon dioxide which buffers the slurry. The pH of the input liquor is about 5.0 to 5.5. Reaction kinetics at these pH's favor the oxidation of sulfite to sulfate and the formation of calcium sulfate dihydrate. A decrease in pH from 7.0 to 4.0 increases the rate of oxidation of sulfite to sulfate approximately 10 times (8).

The double alkali process entails the scrubbing of the flue gas with a solution of sodium sulfite followed by treatment in a separate compartment (a causticiser) of the spent sodium sulfite liquor with hydrated or calcined lime, or limestone. Sulfur oxides are absorbed in the scrubber unit by sodium sulfite (Na₂SO₃) which reacts to form sodium bisulfite (NaHSO₃). Both of these compounds are quite soluble so the scrubber liquid remains clear and scaling is held to a minimum. The spent sodium bisulfite solution is regenerated by being mixed with calcium hydroxide (Ca(OH)₂) in a causticiser. The sodium bisulfite reacts with the calcium hydroxide to form an insoluble calcium sulfite precipitate which is drawn off, leaving the regenerated sodium sulfite to be recirculated through the scrubber unit. Maximum efficiency of the process occurs between pH 6.0 and 7.0.

FGC sludge characteristics and composition are not only dependent upon the type of scrubbing process used, but are also influenced by many other interrelated factors. The chemical composition of the solid and liquid phases of the sludge is a function of the following parameters: (1) type and composition of fuel, (2) type, design, and operation of the boiler, (3) relation

of fly ash and bottom ash removal systems to scrubber sludge removal, (4) type, design, and operation of the FGC system, and (5) type or composition of the scrubbing reagents and input water. The physical properties of the sludge are largely affected by the same parameters since the physical properties are dependent on the composition (especially the relative amounts of calcium sulfite and sulfate).

The FGC sludges used in this study were selected to be representative of the major scrubber techniques and the major types of coal presently being used. Thus, lime and double alkali process sludges using both eastern (high sulfur) and western (low sulfur) coals are included in this study. Only one sample of limestone process FGC sludge using eastern coal is included.

SELECTION OF SLUDGE PROCESSORS

At the beginning of this project, nine solidification/stabilization processors were selected as candidate fixation firms for the program. A sufficient sample of each waste type was obtained for our laboratory testing program and an aliquot of each waste was provided to each processor for evaluation at their laboratory. The purpose of preliminary evaluation by the processors was to determine compatibility between the solidification process and the residue and to establish optimum formulations for each.

After the preliminary evaluations phases, three processors declined further participation in the FGC solidification project. The remaining processors agreed to fix the residues according to the assignments presented in Table 2.

At the conclusion of this preliminary evaluation period, the remaining processors were scheduled to perform solidification/stabilization for the laboratory and physical testing at U. S. Army Engineer Waterways Experiment Station (WES). This arrangement was made to allow project personnel to observe the actual solidification procedure and to maintain a degree of quality control consistently in all processing methods. All solidification procedures included within the program required a curing time for their product. At the end of the curing time, the processors certified that solidification/stabilization was adequate.

STABILIZATION TECHNIQUES

Each sludge was thoroughly mixed, using an industrial mixer prior to splitting the sludges into subsamples so that identical material would be available to each processor. Samples of the sludges obtained for this study were partitioned into several subsamples. One portion was used for preliminary evaluation by the processors, a portion was used for untreated sludge chemical and physical testing, a portion was utilized for the actual sludge solidification, and the remainder retained for supplementary testing. Sludge samples were stored in sealed plastic containers at room temperature.

The stabilization or fixation processes used in this project generated products which could be classified into two specific groupings. The first was

a soil-like material which was highly variable in particle size and the second was a material capable of being cast into a solid, monolithic block. The solidification procedure used in the first group called for casting the treated sludge in square molds containing an adequate volume for testing purposes (122 x 122 x 9 cm). The molds were covered, and after curing for thirty days, the treated samples were broken into smaller sized lumps or pieces (about 5 cm in diameter) and loaded into the leaching columns without further packing (Figure 1). The second group of samples was molded in 7.6-cm diameter, paraffin-coated tubes which were 122 cm in length. After curing, the tubes were removed and the resulting cores were used for chemical and physical testing.

Complete details of the solidification procedures is given in an interim report (9). For the purposes of this report, only a brief summary will be presented. A summary of formulations and column loadings (for selected columns) are given in Table 3.

Process A

Process A, which is patented, used fly ash and a lime additive to produce a pozzolan product. All FCC sludges were fixed by the processor. A bituminous fly ash was used in processing the eastern coal FCC sludges (100, 400, and 500) and a subbituminous fly ash was used in processing western coal FCC sludges (600 and 1000). The amount of fly ash added is related to the amount of water in the sludge. An advantage of this process is the availability of fly ash at power plants producing scrubber sludges. The proportions of additives and FCC sludge are such that the final solidified product contains approximately 20 percent water by weight.

The sludge and fixation agents were mixed in a 0.14-m^3 (5-ft³) mortar mixer. The product was then placed into cylindrical molds, covered, and allowed to cure for 30 days. Subsequent inspection of the solid specimens revealed that curing in the molds under dry conditions had produced cracks, a situation which the processor felt was not representative of this process. A second batch was poured at the processor's laboratories. In this case, the specimens were placed in shorter tubes (7.6 cm x 40.6 cm) and cured under humid conditions to prevent cracking. The fixed specimens were then shipped to WES for chemical and physical testing. This processor chose not to reveal the specific additive-to-sludge ratios; however, the percentage of dry sludge solids for each fixed specimen was 49 percent for sludges 100, 400, and 500; 57 percent for sludge 600; and 35 percent for sludge 1000. These mixes are slightly different from larger scale preparations because of the need to work with small molds. In a field scale operation, placement and consolidation of the sludges would likely be done with construction equipment, requiring a stiffer (lower moisture content) sludge mix. While details of this process were not revealed, the process would generally be classified as a lime/fly ash pozzolan.

Process B

Process B, which is also patented, uses two additives to produce a material of soil-like consistency. Since the relative proportions of reagents in the final mix determine the physical properties of the fixed product the

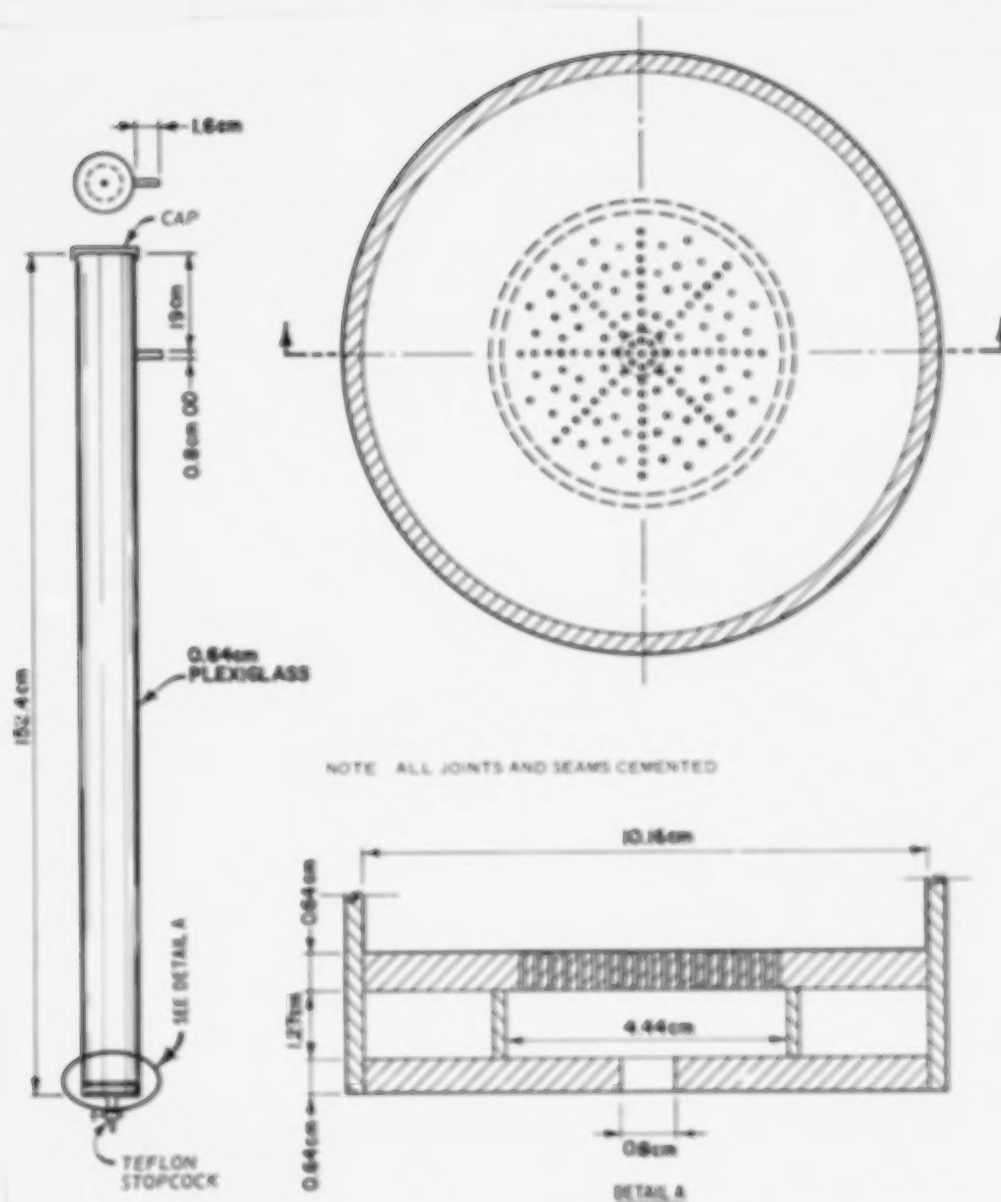


Figure 1. Leaching column design and detail.

TABLE 3. FORMULATION AND COLUMN LOADING FOR FLUE GAS CLEANING SLUDGES
(PRIORITY COLUMNS)

Sludge Number	% Dry Sludge Solids in Product	Wt. Product in Column (g)	Wt. Dry Sludge Solids in Columns (g)
<u>Untreated Sludges</u>			
100R*	59	12,670	7470
400R	55	12,730	7060
500R	52	13,490	7030
600R	72	10,730	7750
1000R	41	13,080	5420
<u>Process A</u>			
100A	49	7,540	3690
400A	49	7,770	3810
500A	49	7,345	3600
600A	57	8,695	4960
1000A	35	7,700	2760
<u>Process B</u>			
100B	35	7,740	2700
400B	33	7,380	2440
500B	40	7,870	3130
600B	29	6,870	2010
1000B	37	7,920	2920
<u>Process E</u>			
100E	34	8,570	2890
400E	34	5,855	2000
500E	31	9,400	2880
600E	42	9,590	4040
1000E	18	7,670	1410
<u>Process F</u>			
600F	36	8,510	3070
<u>Process G</u>			
100G	20	4,690	920
400G	17	4,445	760
500G	11	3,530	370
600G	20	3,800	740
1000G	10	4,260	420

* Letter following sludge number indicates either untreated (R) or treatment process used (A, B, E, F, or G).

consistency of the end product can be regulated to best effect pollutant immobilization, or produce strength properties consistent with the intended use of the fixed sludge. In most cases for stabilizing waste for landfill disposal, a soil-like material, which is the most cost-effective product, is produced.

For this study, the sludge was mixed in 35- to 50-liter batches using an industrial paddle mixer. Cement (Portland Type I) was added to the sludge at a rate of 1-2 percent of the wet weight of the sludge. Then a soluble silicate was added slowly to the mixture at a rate of 2-3 percent of the wet weight of the sludge. Finally, lime was added, when necessary, to raise the pH to approximately 7. Molds 122 cm square and 9 cm high were used to hold the processed sludge for curing. A polyethylene cover was put over the samples during the 12-day curing period to prevent cracking that could be caused by rapid, uneven drying. The curing materials were broken and irregular chunks, 2 to 5 cm in size, were placed in the columns without compaction. All sludges were treated with this process. Process B would be classed as a cement/soluble silicate solidification system.

Process E

Process E used cement and fly ash, which are readily available commercial materials, as additives to convert waste sludge into a hardened product similar to concrete. Several sludge additive combinations were evaluated for each sludge type. The optimum formulation was based solely on minimum leachability without regard to economic considerations or strength of product. All FGC sludges were treated by this process.

Treated samples for this study were prepared in 75-liter batches. Mixing was done with an industrial paddle mixer, except in the case of sludge 500, for which a small concrete mixer (0.1 m³) was used. After thoroughly mixing the reagents with the sludge, the mixture was poured into cylindrical molds and allowed to cure for 30 days at room temperature before testing. Process E is basically a cement/fly ash solidification system.

Process F

Process F mixes a patented additive with a sludge at a pH adjusted to settle the solids in the slurry. The additive is a cementitious product derived from basic, glassy blast furnace slag.

Only limestone process sludges (100 and 600) were solidified using this process. The sludge pH was adjusted to 12.5 with lime. A dry powder additive was added slowly up to 10 percent of the weight of dry sludge solids and allowed to mix thoroughly with the sludge. The mixture was poured into cylindrical molds. The solid mass cured in the presence of the supernatant for approximately 30 days, forming a hardened clay-like material. All the tubes were covered in polyethylene film to maintain a humid environment for curing the specimens. The relatively large amount of free liquid formed by separation of the solids in the tubes resulted in some leakage of liquid through the walls of the mold. This reduced the amount of free supernatant over the samples; nevertheless, the samples remained moist and cured to the

satisfaction of the processor. Process F would be classed as a slag-based, pozzolanic process.

Process G

Process G was a stabilization technique in which waste sludge was mixed with cement kiln-dust, which is itself a waste product from the cement industry. The pH of the mixture is then lowered with either waste sulfuric or phosphoric acid. All of the FGC sludges were processed by Process G using this solidification procedure. Mixing was done with an industrial paddle-mixer. The mixtures were cured in cylindrical molds for 14 days under temperature- and moisture-controlled conditions. Process G would be classed as pH adjustment process which produces a plaster-like product.

LEACHING COLUMN DESIGN

The primary concern in ultimate disposal of FGC sludges is the rate of pollutant migration into the surrounding groundwater (10). Therefore, the leaching columns of this study are designed to simulate leaching from sludges buried in an unlined, water-saturated landfill. This leaching test is aimed at measuring the rate of pollutant movement into an aqueous medium under conditions closely simulating those encountered in the field.

The columns were constructed from materials that were inert with respect to the sludge specimens and leachates. The leaching columns (Figures 1 and 2) were made from 152-cm lengths of 10.2-cm I.D. plexiglass tubing. The inlet port was located 19 cm below the top of the column, providing space for a fluid head of 2.5 cm on top of the sample. The tops of the columns were covered to prevent contamination by dust from the air. The volume of these columns was approximately 10 liters. The bottoms of the columns were sealed and a Teflon stopcock was installed at the lower end as a leachate drain. A perforated plate was cemented into the tube above the stopcock, leaving a 2.5-cm-deep collecting well between the outlet and the bottom of the sample (Detail A, Figure 1). A 7.6-cm layer of 0.64-cm-diameter polypropylene pellets was placed in the bottom of each column to retard movement of the sludge into the leachate collection system. Flow through the column was regulated by the stopcock to maintain a fluid velocity of approximately 1×10^{-5} cm/sec to simulate the flow rate through a raw sludge or fine silt. Sample collection was made in 4.5-liter polypropylene containers which were sealed with parafilm.

The treated sludges which were cast into cylinders were placed into the leaching columns and the space between the sludge and the column wall (approximately 1.3 cm) was filled with polypropylene pellets. This created a dispersed flow of liquid around the sludge samples. The fixed sludges which were not cast into cylinders by the processor (Processor B) were taken from the large molds, broken into smaller pieces, and loaded directly into the columns with no pellet packing. The raw sludges were poured into the columns as a slurry. In all cases, the leaching fluid was back-flooded into each column from the bottom to remove any air spaces. The specimens were maintained in a saturated-flow condition throughout the experiments. All sample columns were set up in triplicate.

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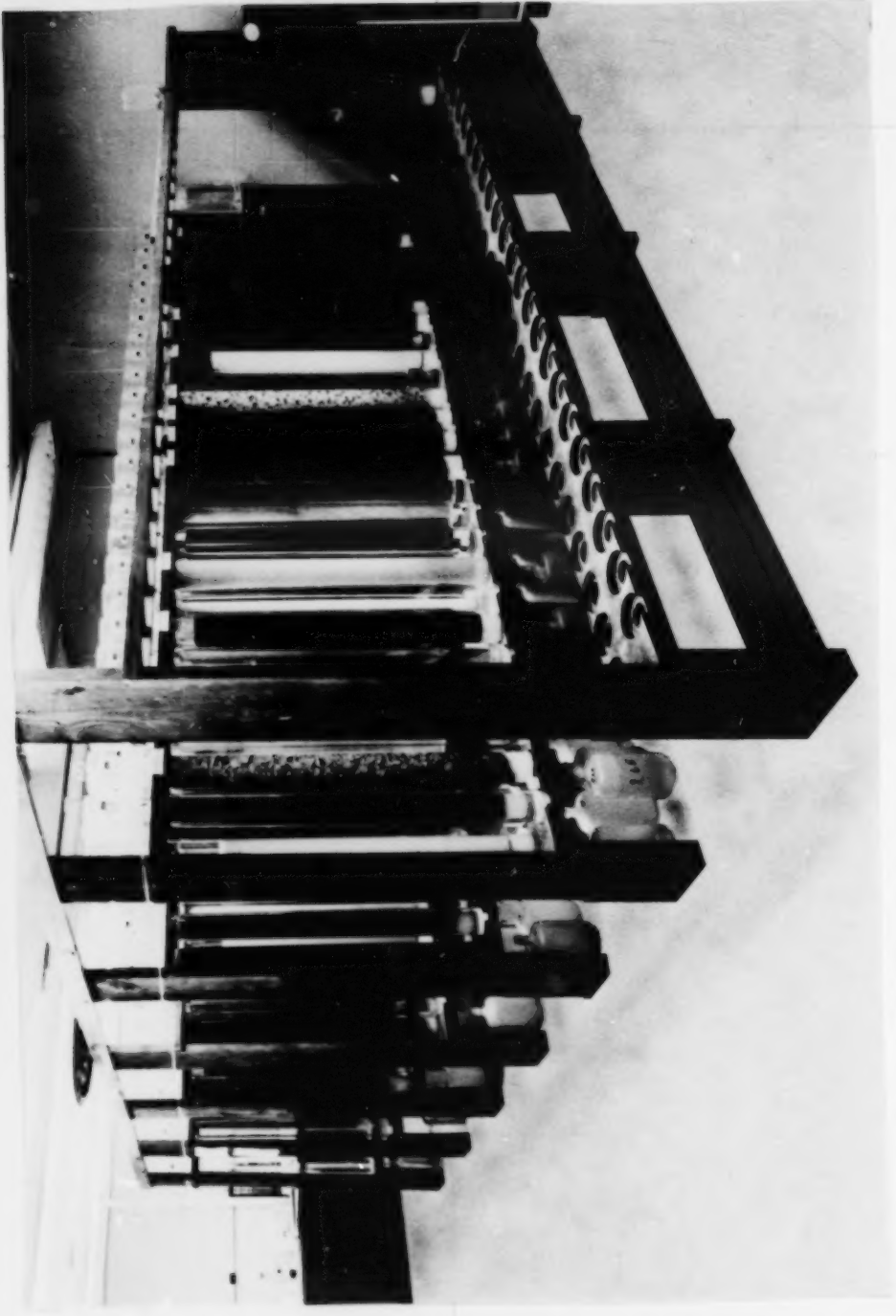


Figure 2. Sample leaching columns in place in racks.

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The leaching fluid used in the testing was deionized water saturated with carbon dioxide at pH 4.5-5.0. All materials used in the leach fluid distribution system were either polypropylene or Teflon to minimize any contamination during the testing. The leaching columns were randomly assigned within a rack system. Each rack of columns was fed from a constant head reservoir at one end of the rack. These reservoirs were in turn connected in series to a central reservoir of the leaching fluid in which the carbon dioxide was equilibrated with the fluid.

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Two types of experimental controls were incorporated into the leaching test. One type of control consisted of each of the untreated sludges which were leached in the same fashion as the solidified sludges. The other type of control consisted of leaching columns with and without the plastic pellets (blank columns). The leaching fluid was also sampled periodically. Corrections were made for background effects of the leach fluid and column apparatus (in all cases, these blank corrections were insignificantly small). Prior to loading the columns with samples, all columns were washed with a laboratory detergent and rinsed with dilute hydrochloric acid. The entire apparatus was flushed before filling. No provisions were made to retard biological activity within the leaching apparatus. Certain organisms (bacteria and algae) did become established in some of the columns.

One column from each triplicate set of treated and untreated sludge columns was selected randomly to be studied using more sensitive and expensive analytic techniques. This set of selected columns provides the basis for judging the performance of the solidification processes, and will be referred to as priority columns (Table 3). Data from the non-priority columns (Appendix A) were used to confirm trends and conclusions derived from examination of priority column data.

The actual weight of fixed product loaded into each of the selected, or priority, columns along with the weight and percent of dry sludge solids in the product, are shown for FGD sludges in Table 3.

Photographs of the raw and fixed sludges used in this study are shown in Figures 3-7. The treated sludges are in the form which was loaded into the leaching column. Note that processes A, E, and F produced excellent cylindrical shapes from the mold; process G material usually contained many voids and uneven surfaces. The material from process B is shown in chunks. These were broken from the large samples supplied by the vendor.

CHEMICAL ANALYSES

Leachate flowed from the columns continuously and was collected in 4.5-liter plastic bottles. At each sampling interval, after the pH, conductivity and volume of collected leachate was measured, each sample was split into aliquots of appropriate volume. Each aliquot was preserved using EPA-accepted techniques (11). Details of sample preservation are given in Table 4. All samples were held at 4° C until analyzed. For samples whose volume was too small to make all analyses, subsamples were first made up for metal analysis, then anion analysis, cyanide, and then total organic carbon

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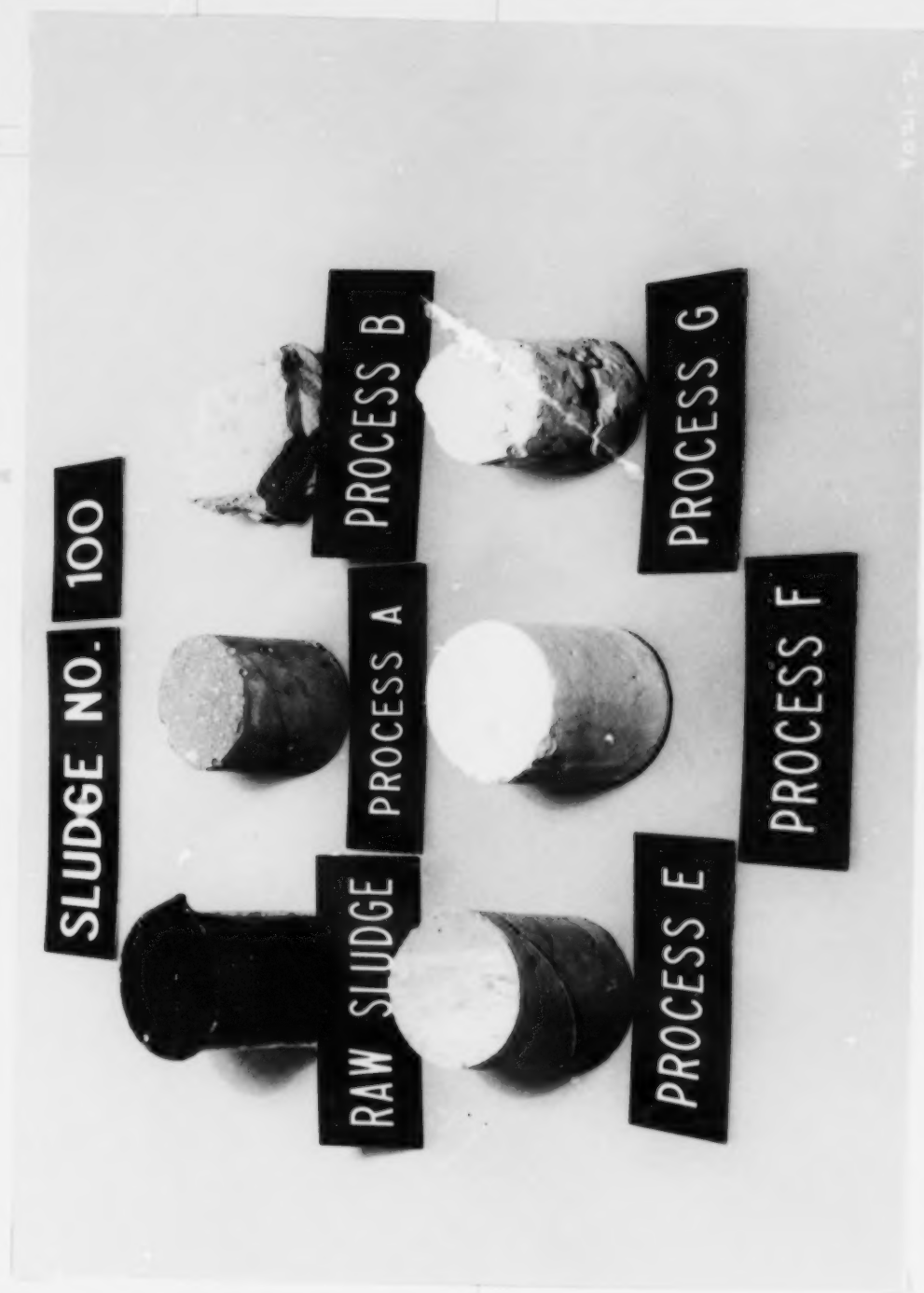


Figure 3. Untreated (raw) and solidified FGC wastes from a lime process scrubber, eastern coal (No. 100).

SLUDGE NO. 400

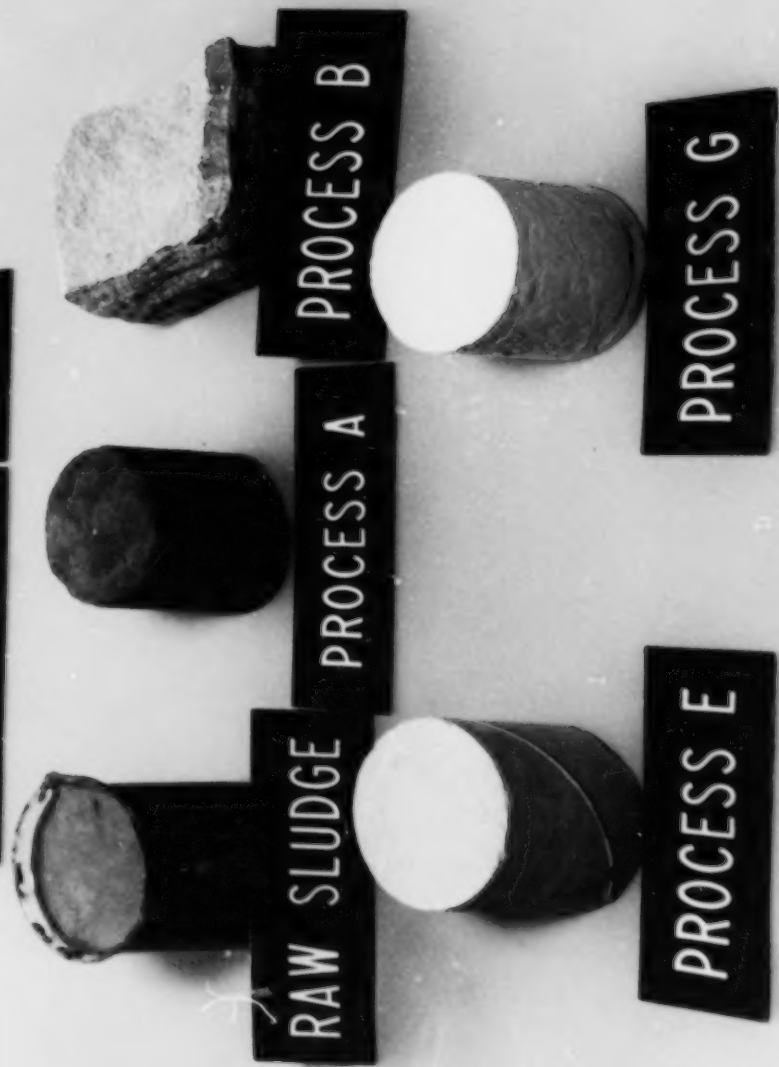


Figure 4. Untreated (raw) and solidified FGC wastes from a limestone process scrubber, eastern coal (No. 400).



Figure 5. Untreated (raw) and solidified FGC wastes from a double alkali process scrubber, eastern coal (No. 500).

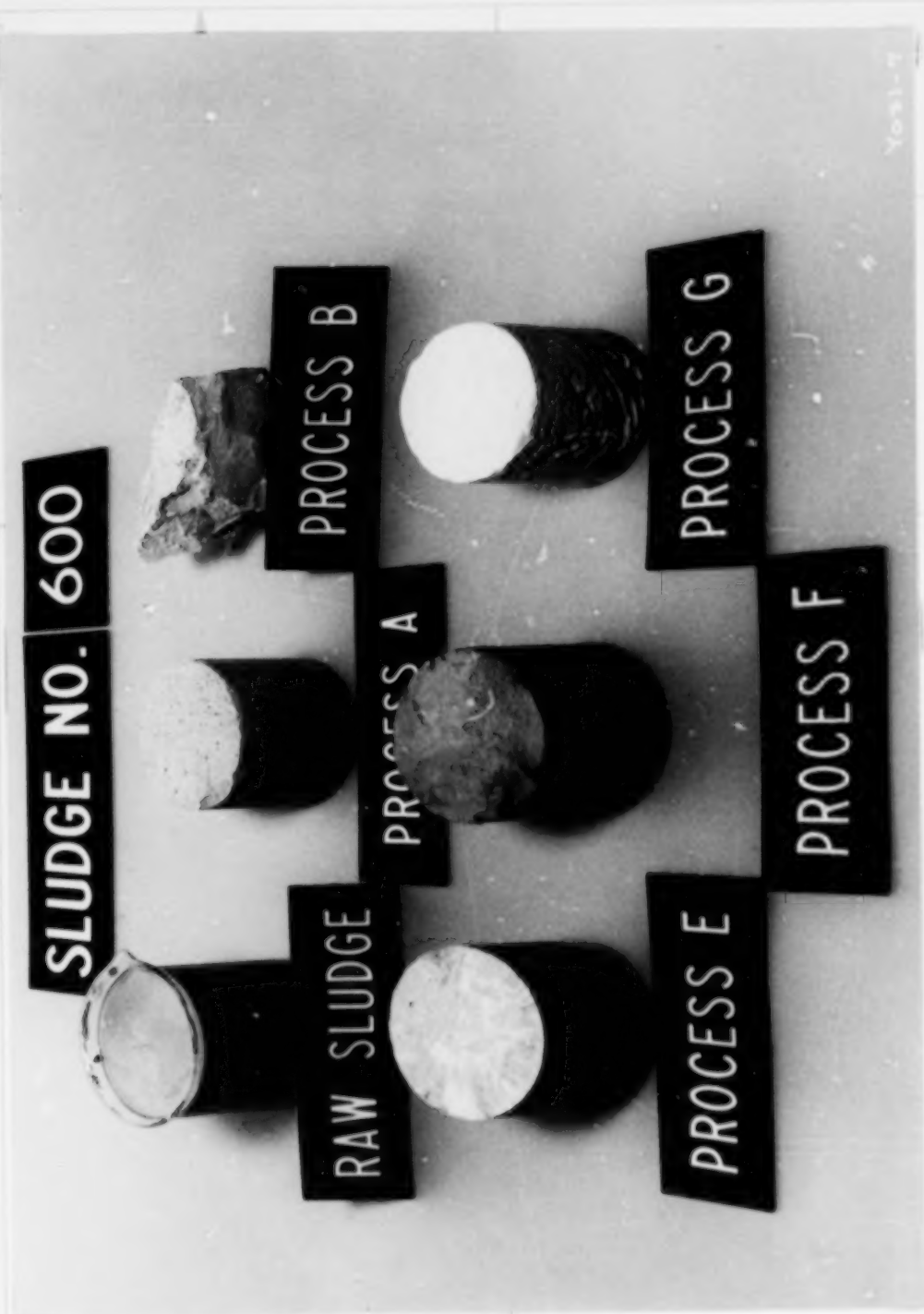


Figure 6. Untreated (raw) and solidified FCC wastes from a lime process scrubber, western coal (No. 600).



Figure 7. Untreated (raw) and solidified FGC wastes from a double alkali process scrubber, western coal (No. 1000).

TABLE 4. METHODS OF PRESERVATION OF LEACHATE SAMPLES

Parameters to be Determined	Method of Preservation
Metals	Samples acidified to pH 1.0 with ultra-pure nitric acid
Cyanide	Samples brought to pH 11.0 with sodium hydroxide
Total Organic Carbon	Samples acidified with hydrochloric acid and held at 4°C
Chemical Oxygen Demand	Samples acidified with sulfuric acid and held at 4°C
Anions	Sample held at 4°C

TABLE 5. LIMITS OF DETECTION FOR METALS IN LOW AND HIGH RESOLUTION ANALYTICAL PROCEDURES

Metal	Detection Limits for Low Resolution (ppm) (Non-priority Columns)	Detection Limits for High Resolution (ppm) (Priority Columns)
As	2.0	0.005
Be	0.05	0.005
Ca	0.2	0.005
Cd	0.05	0.003
Cr	0.5	0.003
Cu	0.2	0.003
Fe	0.3	0.003
Mg	0.02	0.005
Mn	0.1	0.002
Ni	0.3	0.005
Pb	1.0	0.002
Se	1.0	0.005
Zn	1.0	0.014

Note: Low resolution analyzed by flame atomic absorption; high resolution analyzed by heat-graphite-atomizer atomic absorption.

and chemical oxygen demand. Parameters selected for analysis include all potential pollutants. As mentioned previously, one of the three replicate columns for each sludge type and treatment process (termed the priority column) was selected at random for high-resolution metal analysis. The remaining two replicates (nonpriority) were subjected to low-resolution metal analysis. The limits of detection for these two levels of analytical techniques for metals are shown in Table 5. The method of analysis and detection limits for other parameters are given in Table 6.

Leachate samples were collected from each of the columns at logarithmic time intervals for a minimum of two years. Many of the priority columns were sampled for more than two years. This logarithmic sampling schedule was selected to best reflect the leach column performance that would be predicted by mass transport theory. Leaching systems are generally characterized by a stable or monotonically decreasing leach rate which approached some limiting value. Thus the initial sampling periods are more critical and the columns are best sampled at increasing intervals.

An extensive quality control program was implemented to assure precision and accuracy within the analytical system. The program included replicate determinations and spiked additions to representative leachate samples, and the periodic analysis of standards obtained from the EPA (MERL) at Cincinnati, OH, or National Bureau of Standards. Quality control efforts were concentrated on metals, since they represent the major group of pollutants of interest in the project.

TABLE 6. METHODS OF ANALYSIS FOR ANIONS AND OTHER PARAMETERS
AND THEIR LIMITS OF DETECTION

Parameter	Method of Analyses	Limit of Detection (mg/l)
Total Organic Carbon (TOC)	Dohrmann, DC-50, Carbon Analyzer	1
Chemical Oxygen Demand (COD)	Technicon II Analyzer	5
Chloride	Manual Titration	5
Cyanide	Technicon Analyzer	0.01
Mercury	Zeeman Atomic Absorption	0.002
Nitrate-N	Technicon Analyzer	0.01
Nitrite-N	Technicon Analyzer	0.01
Sulfate	UV-Visible Spectroscopy	8
Sulfite	Manual Titration	3

SECTION 5

PHYSICAL AND ENGINEERING PROPERTIES OF TREATED AND UNTREATED FCC WASTES

BACKGROUND

A description of laboratory tests used to determine the physical properties of untreated and treated sludges and the results of the tests are only briefly presented here as they are the subject of a separate report (12). Tests commonly used in determining the properties of soil and concrete were performed on the untreated and solidified sludges to determine their physical and engineering properties. The use of standard tests allowed comparison of sludge properties with those of common materials whose properties are described in the literature. Procedures used to test untreated and solidified sludges were selected on the basis of the appearance of the materials (i.e., soil-like or concrete-like). The testing schedule is shown in Table 7. Standard test procedures were modified as necessary to prevent the alteration of sludge properties during testing and to accommodate nonstandard test specimens. Specific deviations from standard procedures are described where appropriate.

PHYSICAL PROPERTY TESTS AND RESULTS

Grain-size Analysis

The particle-size distributions of samples of untreated sludges were determined by two grain-size analysis techniques, the results of which were combined. A sieve analysis was performed on that fraction of each sludge sample larger than 0.074 mm (#200 sieve), and a hydrometer analysis was performed on the finer fraction. Test procedures are described in Appendix V of Engineer Manual (EM) 1110-2-1906 (13) and in American Society for Testing and Materials (ASTM) standard test D422-63 (14). Samples whose grain-size distributions were determined were prepared in accordance with the specification of ASTM D421-58 (14). Results from the combined sieve and hydrometer analyses which were used to determine the grain-size distribution of the untreated sludges are presented in Figures 8-12 as grain size (in mm) versus percent fines by weight.

The grain-size analysis of the untreated sludges illustrates the basis of some of the handling, dewatering, and disposal problems encountered with the untreated FCC sludges. The median grain sizes of the untreated sludges range from 8 to 40 microns; these are comparable to fine clays. A very large proportion of the sludges will pass the standard #200 sieve (0.074 mm)--97 percent of sludge 100, 72 percent of sludge 400, 95 percent of 500, 97 percent of 600 and 100 percent of sludge 1000. Such grain sizes are usually indicative of

TABLE 7. TEST SCHEDULE FOR TREATED AND UNTREATED FGC SLUDGES

Type of Test	Untreated Sludges	Solidification Processes				
		A	B	E	F	G
<u>Physical Tests</u>						
Grain-size analysis	X		X		X	
Specific gravity of solids	X	X	X	X	X	X
Water content	X	X	X	X	X	X
Bulk and dry unit weight	X	X	X	X	X	X
Porosity and void ratio	X	X	X	X	X	X
Liquid limit	X		X			
Plastic limit	X		X			
<u>Engineering Tests</u>						
15-blow compaction test			X			
Unconfined compression test		X	X	X	X	X
Permeability test	X	X	X	X	X	X
Freeze-thaw test		X	X	X	X	X
Wet-dry test		X	X	X	X	X

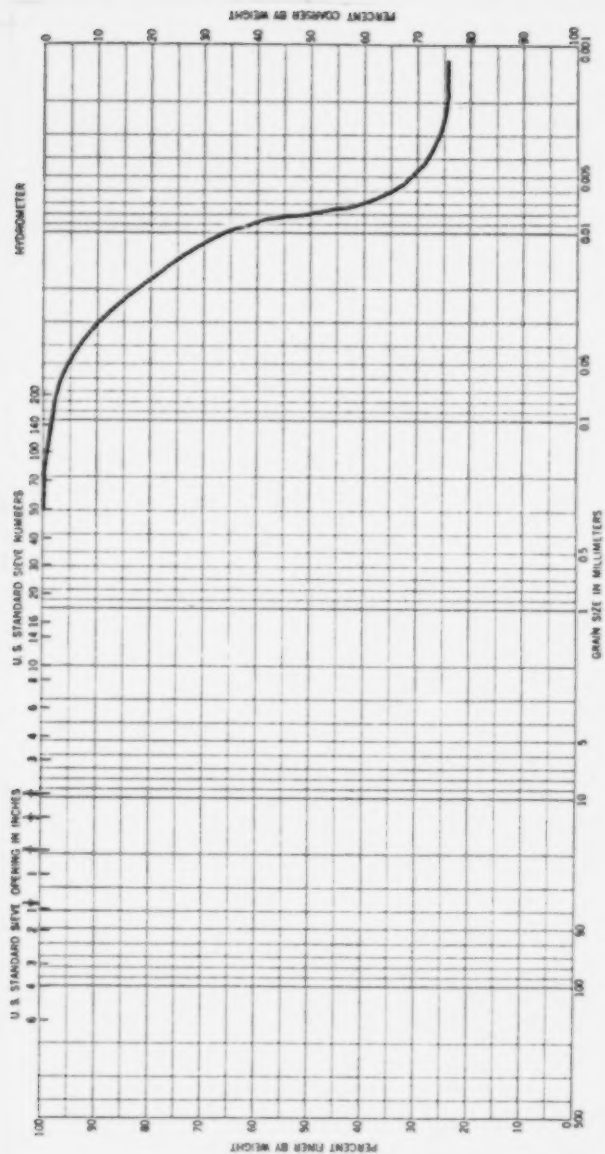


Figure 8. Grain-size distribution of untreated FCC sludge from lime process, eastern coal (No. 100).

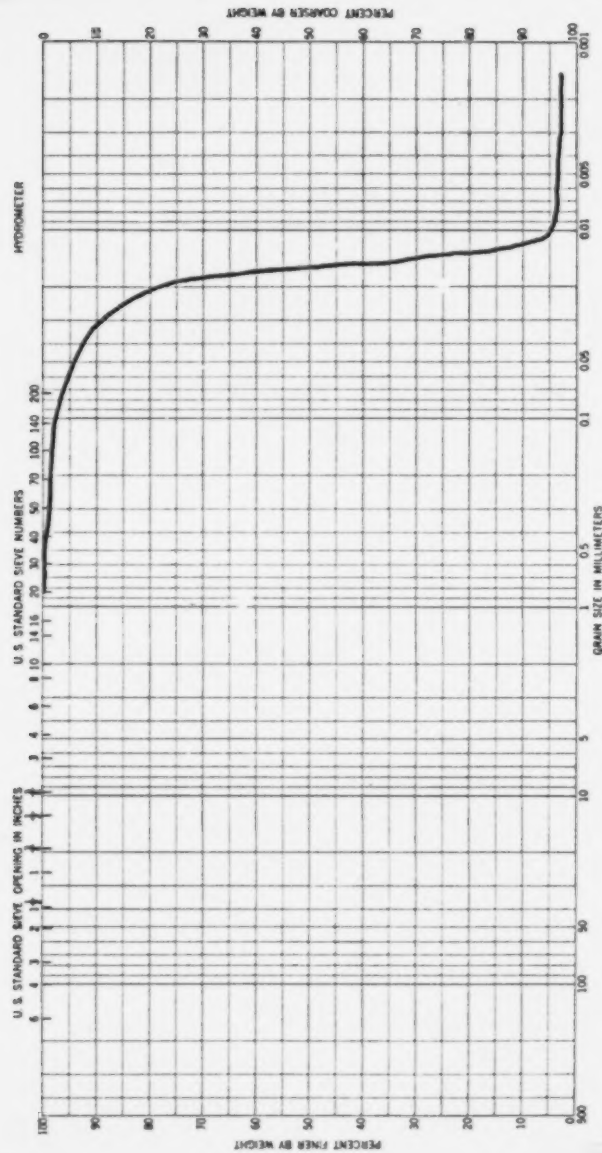
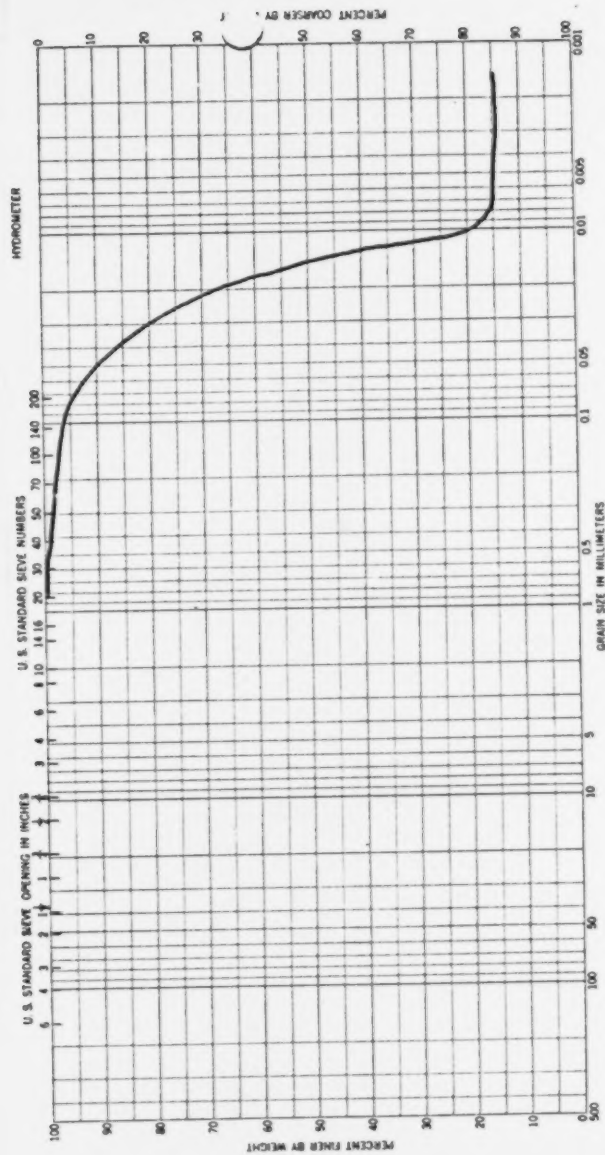


Figure 9. Grain-size distribution of untreated FCC sludge from limestone process, eastern coal (No. 400).



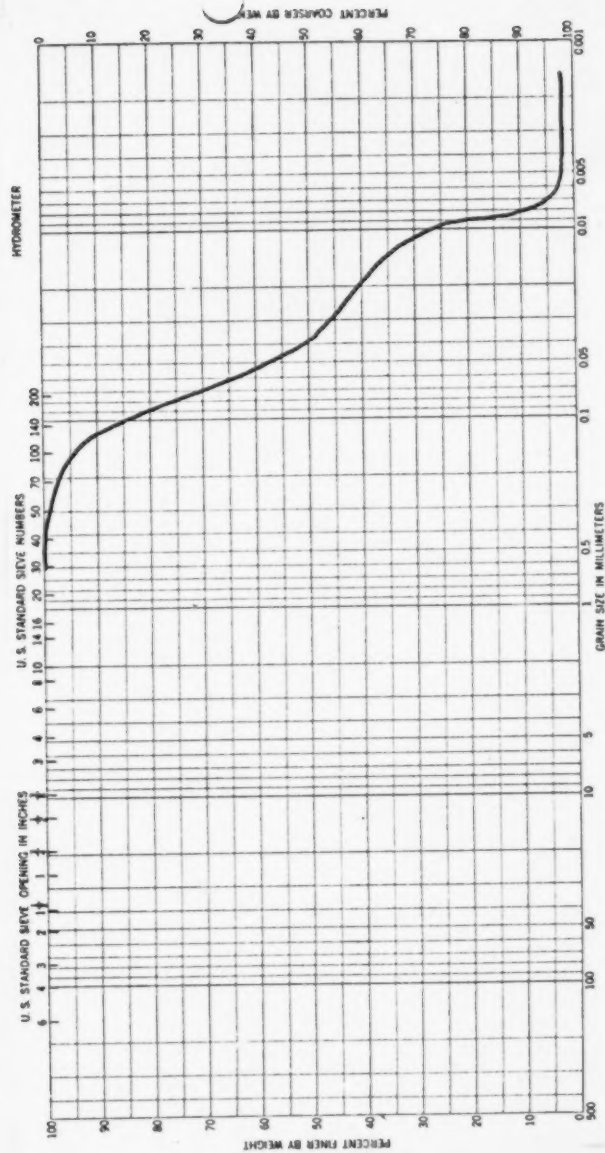


Figure 11. Grain-size distribution of untreated FGC sludge from lime process, western coal (No. 600).

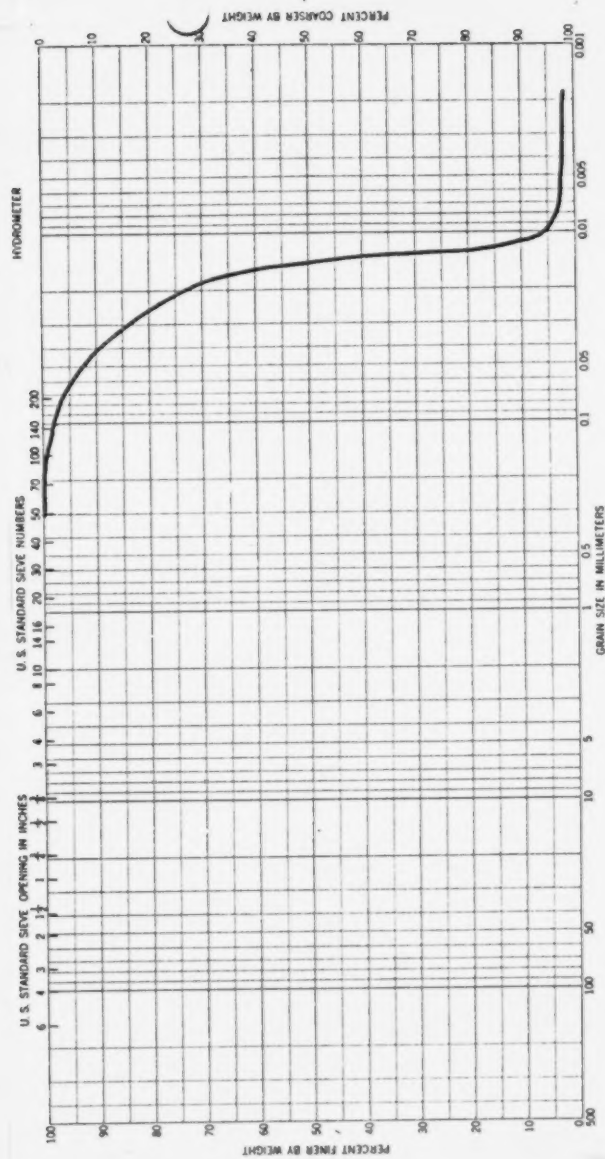


Figure 12. Grain-size distribution of untreated FCC sludge from double alkali process, western coal (No. 1000).

materials displaying low permeability, low strength, and high compressibility. Severe dewatering and wind-blown air pollution (dust) problems are associated with their handling and disposal.

Specific Gravity of Solids

The specific gravity of solids for raw and fixed sludges is defined as the ratio of the unit weight of dry sludge solids to the unit weight of water. The test procedure used to determine specific gravity is given in Appendix IV of EM 1110-2-1906 (13) and in ASTM D854-58 (14). Tests were performed using and oven at a drying temperature of $60 \pm 5^\circ\text{C}$ due to loss of water of hydration at higher oven temperatures.

The specific gravities of raw and fixed sludges are given in Table 8.

TABLE 8. SPECIFIC GRAVITIES OF TREATED AND UNTREATED FGC SLUDGES

Sludge No.	Untreated	Specific Gravity				
		Solidification Process				
		A	B	E	F	G
100	2.41	2.41	2.58	2.54	-	2.70
400	2.51	2.47	2.35	2.55	-	2.49
500	2.85	2.57	2.74	2.72	-	2.50
600	2.53	2.52	2.57	2.57	2.46	2.41
1000	2.99	2.45	2.84	2.61	-	2.44

Note: Dashes indicate processors did not treat that sludge.

Values of specific gravities for the raw sludges varied from 2.41 to 3.96, a range extending somewhat higher than that of typical soils. In general, the various solidification processes caused only slight changes in specific gravity. Process A resulted in either lower or unchanged values for all sludges fixed. Processes B, E, F, and G caused small and variable changes, resulting in values both slightly higher and lower than the specific gravity of the corresponding untreated sludge. In general, changes in specific gravity did not seem to be dependent on the type of sludge processed, although sludges 100 and 500 showed decreases for all processes tested.

Water Content (Dry Weight Basis)

The water content of a sludge sample is defined as the ratio of the weight of water to the weight of solids in the sample and normally is expressed as a

percentage. Calculated in this way, it is termed "dry weight basis water content." The water contents of fixed sludges were determined by the method presented in Appendix I of EM 1110-2-1906 (13) and in ASTM D2216-71 (14). Test samples of known weight were oven dried at 60°C to constant weight. The weight loss upon drying was attributed to loss of interstitial water. The water content of samples of solidified sludge are listed in Table 9. These data indicate that the relative amount of available interstitial water after fixation is greatly process-dependent. Sludge solidified by Process B exhibited water contents comparable to those of natural soils. Processes A, E, F, and G produced treated sludges with a wide range of properties, but mostly resembling concrete, with low interstitial water content.

Bulk and Dry Unit Weight

The bulk weight of a sludge sample is defined as the ratio of total weight (solids and water) to total volume. Dry unit weight is defined as the ratio of oven dried (60°C) weight to total volume. The standard procedures for both tests are found in Appendix II of EM 1110-2-1906 (13). Volumes were computed using linear measurements of a regularly shaped mass obtained by trimming or cutting.

The bulk unit weight and oven-dry unit weights of the fixed sludges are presented in Table 9. Processes A and B yielded materials whose bulk weight values are in the range typical of soils and whose bulk and dry unit weights differ, as would those of soils. The remaining processes resulted in materials having only slight differences between bulk and dry unit weight. These small differences showed no consistent pattern.

Porosity and Void Ratio

The void ratio of a sludge sample is defined as the ratio of the volume of voids to the volume of solids and is normally expressed as a fraction. Porosity is defined as the ratio of the volume of voids to the total volume and is expressed as a percentage. The standard test procedures for determining these parameters are found in Appendix II of EM 1110-2-1906 (13).

Values found for the solidified sludges are shown in Table 9. Process B yielded soil-like material with high void ratio and high porosity. The other treated materials showed porosities and void ratio in the range of low-strength concrete.

Atterberg Limits

Atterberg limit tests were performed on samples of treated and untreated sludges to determine the plasticity of the materials. The tests are designed to determine the limiting water contents, termed the plastic limit and liquid limit at which the material exhibits plastic and liquid behavior. The plasticity index, or range of plastic behavior, is defined as the difference between the liquid and plastic limits and is normally expressed as a percentage. Test procedures for determining these parameters are presented in Appendix III and IIIA of EM 1110-2-1906 (13) and ASTM standard tests D424-59

TABLE 9. PHYSICAL PROPERTIES OF TREATED FGC SLUDGES

Process and Sludge Number	Water Content (%)	Bulk Unit Weight (kg/m^3)	Dry Unit Weight (kg/m^3)	Void Ratio	Porosity (%)
Process A					
100A	23.8	1650	1300	0.860	46.2
400A	24.2	1740	1400	0.768	43.4
500A	41.4	1530	1080	1.377	57.9
600A	15.6	1750	1520	0.663	39.9
1000A	23.7	1550	1250	0.958	48.9
Process B					
100B	77.5	1230	700	2.711	73.1
400B	69.5	1430	840	1.794	64.2
500B	67.3	1460	870	2.150	68.3
600B	88.9	1280	675	2.811	73.8
1000B	70.9	1310	765	2.717	73.1
Process E					
100E	6.4	1620	1520	0.671	40.2
400E	8.7	1330	1220	1.072	52.2
500E	6.5	1590	1495	0.822	45.1
600E	10.7	1780	1610	0.601	37.5
1000E	0.7	1330	1315	0.987	49.7
Process F					
600F	3.7	1300	1250	0.996	49.1
Process G					
400G	10.7	1010	910	1.737	63.5
500G	7.6	840	780	2.198	68.7
600G	13.3	915	810	1.991	66.6
1000G	17.0	1090	930	1.617	61.8

Note: All tests conducted with 60°C drying oven; all data are average of three determinations on separate samples.

(14) and D423-66 (14). The plastic limit is defined as the water content at which the sludge will start to crumble when rolled into a 3-mm thread under the palm of the hand. The liquid limit is defined as the lowest water content at which two halves of a soil specimen separated by a groove of standard dimensions will close along a distance of 12 mm under the impact of 25 blows of a standard device.

The Atterberg limits of all untreated sludges and sludges treated using process B were determined. Values for these parameters are listed in Table 10.

TABLE 10. ATTERBERG LIMITS OF UNTREATED SLUDGES AND THOSE TREATED BY PROCESS B

Process and Sludge Number	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
<u>Untreated Sludges</u>			
100R	42	36	6
400R	51	38	13
500R	95	67	28
600R	NP*	NP	NP
1000R	44	37	7
<u>Process B</u>			
100B	NP	NP	NP
400B	100	85	15
500B	80	70	10
600B	108	100	8
1000B	64	57	7

* NP = Non-Plastic.

This fixation process increased the liquid limit and plastic limit of the sludge in some cases and decreased them in others. No consistent pattern was evident.

ENGINEERING PROPERTIES TEST AND RESULTS

Compaction Tests

The 15-blow compaction test was performed on the appropriate solidified sludges to determine the optimum water content for compaction and the unit weights which could be expected from field compaction in a landfill. The test

procedure is presented in Appendix VI of EM 1110-2-1906 (13) and is identical to the ASTM D698-70 (14) procedure except that only 15 blows are employed. A 10-cm-diameter cylindrical mold was filled with three equal layers of solidified sludge. Each layer was compacted with 15 uniformly distributed blows from a 2.5-kg hammer with a 30-cm drop. Following compaction, the dry unit weight and dry weight basis water content were measured. The entire test was then repeated with a small amount of water added to increase the water content. Results of this test are expressed by plotting dry unit weight versus water content. The optimum water content for the compaction test was taken as that water content at which the dry unit weight was maximal. The test, as described, simulates the compactive effort available when the sludges are placed in a landfill using typically available compacting equipment,³ such as bulldozers. This compactive effort is equivalent to 3.5×10^6 N-m/m³.

Only sludges solidified by process B were subjected to this test. Values found for dry unit weights and optimum water content for these sludges are shown in Table 11. Optimum water content for sludges 100B, 500B, 600B, and 1000B are high when compared to values for typical soils; sludge 400B more nearly matches typical soil values.

TABLE 11. CHANGES IN DRY UNIT WEIGHT WITH COMPACTION AND OPTIMUM WATER CONTENT OF SLUDGES TREATED BY PROCESS B

Sludge No.	Dry Unit Weight (60°C Oven)			Optimum Water Content (%)
	Without Compaction (kg/m ³)	Maximum After Compaction* (kg/m ³)	Change Due To Compaction (kg/m ³)	
100B	700	690	-10	82.5
400B	840	915	+75	47.0
500B	870	825	-45	65.0
600B	675	670	- 5	89.5
1000B	765	810	+45	73.5

* 15-blow compaction test, 3.5×10^6 N-m/m³ compactive effort.

Unconfined Compression Tests

Unconfined compression tests were performed on all treated sludge samples. This test determines the uniaxial, unconfined compressive strength of a cohesive or cemented material by loading a cylindrical specimen axially until failure.

The highest compressive stress sustained by the material is considered the unconfined compressive strength of that sample. The test procedure is found in Appendix XI of EM 1110-2-1906 (13) and in ASTM D2166-66 (14).

The measured unconfined compressive strength (Table 12) varies greatly between solidification processes and between sludge types. Sludges treated by process B have relatively uniform compressive strengths which are comparable to values for cohesive or cemented soils. Sludges treated by processes A and G resemble low-strength, soil-cement mixtures with two to four times higher compressive strengths than samples from process B. Sludges treated by processes E and F resemble low-strength concretes with one sample (600E) having compressive strengths near 3100 N/cm^2 . Knowledge of the unconfined compressive strength of the solidified sludges provides an estimate of their bearing capacity and their usefulness in construction activities.

The modulus of elasticity (Young's Modulus) is also given in Table 12. It is the ratio of stress to strain for the treated sludge samples (slope of stress-strain curves used to determine the unconfined compressive strength). These data parallel the results from the unconfined compressive strength testing and indicate that the processed sludges resemble cemented soils (B and G) or low-strength concrete (E and F).

Permeability Tests

Two different permeability test procedures were used on the untreated and the solidified sludges. The permeability of the untreated sludges was measured in a falling head test which is designed for fine-grained materials with permeabilities less than 10^{-3} cm/sec . The permeability testing of the solidified sludges is more complex as complete water saturation of the sample must be achieved for the determinations to be accurate. For the solidified samples, a falling head permeability test was carried out in a triaxial compression chamber with a back pressure of 6.9 N/cm^2 . The back pressure was needed to insure complete saturation. Details of these tests and the modifications employed can be found in references 12 and 13.

The permeability coefficients and associated data for the untreated sludges are given in Table 13. The untreated FGC sludges have consistently low permeabilities with coefficients varying between 1.07×10^{-5} and $7.78 \times 10^{-6} \text{ cm/sec}$. However, the void ratios of the sludges vary considerably, from less than one to over four. The lime- and limestone-based sludges have low void ratios (and water content) while both double alkali sludges exhibit very high void ratios (and water contents).

The solidified FGC sludges may be described as having low to very low permeabilities with coefficients varying from 1.08×10^{-5} to an extreme of $4.54 \times 10^{-11} \text{ cm/sec}$ (Table 14). The laboratory permeabilities measured on treated sludge samples would only be true under field conditions in specimens where the material had not cracked or disintegrated in any way and was fully saturated. Cracking or disintegrating greatly increased both permeability and the surface area exposed. Complete saturation of the solidified sludges requires an extremely large head (hydrostatic pressure) or a very long time and

TABLE 12. UNCONFINED COMPRESSION TEST DATA

Process and Sludge No.	Initial Dry Unit Weight (kg/m ³)	Unconfined Compressive Strength (N/cm ²)	Modulus of Elasticity (N/cm ²)
Process A			
100A	1300	69	7.60×10^3
500A	1080	129	2.09×10^4
600A	1520	278	5.17×10^4
1000A	1250	232	7.59×10^4
Process B			
100B	670	15.9	2.46×10^3
400B	1050	30.7	2.51×10^3
500B	935	29.5	6.90×10^3
600B	710	24.3	2.34×10^3
1000B	860	16.0	7.60×10^2
Process E			
100E	1520	1780	3.10×10^5
400E	1330	496	8.69×10^4
500E	1500	1520	2.14×10^5
600E	1610	3100	1.15×10^6
1000E	1330	948	1.69×10^5
Process F			
600F	1120	396	3.45×10^4
Process G			
400G	910	167	6.28×10^4
500G	780	59.3	1.10×10^4
600G	810	86.9	1.13×10^4
1000G	935	99.4	3.64×10^4

TABLE 13. PERMEABILITY DATA FOR UNTREATED FGC SLUDGES

Sludge No.	Percent Solids (%)	Water Content* (%)	Dry Unit Weight (kg/m ³)	Void Ratio	Coefficient of Permeability** (cm/sec)
100R	54.8	82.5	945	1.56	3.61×10^{-5}
	63.1	58.6	1035	1.34	1.07×10^{-5}
400R	51.1	95.7	930	1.71	9.45×10^{-5}
	59.8	67.0	1120	1.23	7.78×10^{-6}
500R	59.2	145	485	4.87	4.37×10^{-5}
	45.0	121	580	3.94	2.50×10^{-5}
600R	69.9	43.0	1390	0.82	2.01×10^{-5}
	77.5	29.4	1660	0.52	1.44×10^{-5}
1000R	40.5	146	695	3.32	8.46×10^{-5}
	42.4	136	785	2.82	6.54×10^{-5}

Note: All drying done in 60°C oven. Two sets of data for each sludge -- samples were tested, vibrated in the tube (densified), and retested.

* Dry weight basis.

** Corrected for water at 20°C.

may never be accomplished in the field. Incomplete saturation lowers the effective permeability of the sample so that the data presented here are representative of the worst case, complete saturation.

Sludge samples solidified using processes B and G appear to be the most permeable overall with permeability coefficients approximating those of the untreated sludges. Processes A and E produced the greatest decreases in permeabilities averaging less than one one-hundredth the permeabilities of the untreated sludges. No pattern of permeability variations is evident between the different sludge types. The solidification process, regardless of the FGC sludge type, controls the permeability.

Durability Tests

Two testing procedures, freeze-thaw and wet-dry, were used to assess the long-term physical stability of the solidified sludges under simulated field conditions. The solidified products used in this study were designed

TABLE 14. PERMEABILITY DATA FOR TREATED FGC SLUDGES

Process and Sludge No.	Percent Solids (%)	Water Content* (%)	Dry Unit Weight (kg/m ³)	Void Ratio	Coefficient of Permeability ** (cm/sec)
<u>Process A</u>					
100A	78.1	28.3	1240	0.96	2.06×10^{-6}
500A	67.6	47.8	1000	1.57	1.12×10^{-7}
600A	86.2	16.1	1480	0.70	4.31×10^{-7}
1000A	78.1	27.8	1180	1.07	8.95×10^{-7}
<u>Process B</u>					
400B	82.6	21.2	1020	1.30	1.08×10^{-5}
500B	65.4	52.7	870	2.16	4.56×10^{-5}
600B	59.2	68.8	712	2.61	3.97×10^{-5}
1000B	58.1	71.9	724	2.93	6.62×10^{-5}
<u>Process E</u>					
400E	91.0	11.3	1160	1.20	2.52×10^{-6}
500E	75.2	33.4	1250	1.18	4.54×10^{-11}
600E	80.0	24.7	1420	0.88	3.57×10^{-8}
1000E	90.1	10.4	1240	1.11	7.33×10^{-7}
<u>Process F</u>					
600F	97.0	3.7	1250	0.97	5.01×10^{-6}
<u>Process G</u>					
400G	93.5	7.7	852	1.93	5.24×10^{-5}
1000G	63.7	56.8	866	1.82	4.05×10^{-5}

Note: All drying done in 60°C oven. Several questionable values have been deleted due to problems with apparatus during tests (100B, 100E, 500G, and 600G).

* Dry weight basis.

** Corrected for water at 20°C.

specifically for disposal in landfill operations where the samples would be buried above the water table, but below the level of frost penetration. The freeze-thaw and wet-dry tests are considered to be accurate indicators of product durability. They do represent worst-case conditions in landfilling and are useful in determining the relative durability of the solidified sludges produced by the processes used in this study.

Freeze-Thaw Test--

Fully cured, solidified sludge samples were subjected to the standard freezing and thawing test used for compacted soil-cement mixtures, ASTM Test D560-57 (14). The test consists of 12 test cycles of 24 hours freezing followed by 23 hours thawing, at which time two firm strokes are applied to all surfaces of the cylindrical sample with a wire scratch brush. Performance in the test is evaluated by weight loss during the test or by the number of cycles necessary to cause disintegration of the sample.

Wet-Dry Test--

The wet-dry test is similar to the freeze-thaw test, but is designed to be a much less severe treatment of the test samples. Cured samples (7.5-cm cylinders) were subjected to 12 cycles each consisting of 5 hours submerged in distilled water, followed by 42 hours in a 60°C drying oven. After each cycle, two firm strokes were applied to each surface with a wire scratch brush. Results are reported either as the weight loss after 12 cycles or as the number of cycles required for complete disintegration of the sample. Detailed test procedures are found in ASTM D559-57 (14).

Results of both durability tests are given in Table 15. In the freeze-thaw test, only two samples stayed intact throughout the test--500E, which lost 26 percent of its weight and 100E, which lost 18 percent of its weight. Eight of the 14 samples disintegrated on the first or second freeze-thaw cycle. The wet-dry results parallel the freeze-thaw data and show considerable damage to the specimens, but to a lesser extent than the freeze-thaw test data. Five of 19 samples disintegrated after 1 or 2 wet-dry cycles; six samples resisted 12 wet-dry cycles, losing between 6 percent and 41 percent of their weight in the test.

Process B produces a soil-like product which withstood no more than three cycles of either test. Sludges solidified by processes A and F did little better, although they withstood several cycles of the tests before disintegrating. Only sludges solidified by process E held up to any degree, having all samples survive the wet-dry tests cycles and half survive the freeze-thaw test cycles.

SUMMARY OF PHYSICAL AND ENGINEERING PROPERTIES

The FGC sludges as prepared for this study show the typical features which have been reported for this type sludge (8): they are made up largely of very small particles with high (greater than 50 percent) water content and low bearing capacity; they have a specific gravity between about 2.4 and 3.0

TABLE 15. RESULTS OF FREEZE-THAW AND WET-DRY DURABILITY TESTING
OF TREATED SLUDGES

Process and Sludge No.	Weight Loss After 12 Test Cycles (%)		Number of Wet-Dry Test Cycles to Fail	Number of Freeze-Thaw Test Cycles to Fail
	Wet-Dry	Freeze-Thaw		
<u>Process A</u>				
100A			3	2
400A			1	-*
500A			6	6
600A			10	-
1000A	41.7			
<u>Process B</u>				
100B			1	1
400B			1	1
500B			2	1
600B			3	2
1000B			1	1
<u>Process E</u>				
100E	15.8			10
400E	15.0			7
500E	10.8	26.6		
600E	21.0			-
1000E	6.6	18.3		
<u>Process F</u>				
600F			6	4
<u>Process G</u>				
400G			5	2
500G			5	-
600G			7	-
1000G			7	2

Note: Weight-loss percentages are average of two specimens; number of test cycles is to failure of first sample.

* - indicates no data available.

and low permeability (averaging about $3 \text{ to } 4 \times 10^{-5} \text{ cm/sec}$). These properties are indicative of a sludge with poor handling and dewatering characteristics.

Solidification, in general, produced a material that resembled either soil-cement mixture or low-strength concrete. Solidification produced no consistent change in specific gravity or water content of the sludges.

Processes A and B yield materials whose bulk and dry unit weights resemble those of soils (and appear to be related as these properties would be in soil). The remaining processes produced materials having very small differences in bulk and dry unit weight (similar to concrete).

Only process B produced a product which could be subjected to Atterberg limit and compaction tests. Comparison of results of Atterberg limit tests of untreated sludges with those treated by process B showed no consistent effect that could be related to the process. In general, optimum water contents determined from the compaction test were higher or equal to values determined for typical soils.

Process B yielded materials that had compressive strengths comparable to those of cohesive or cemented soils. Processes A and G produced materials resembling low-strength soil-cement with two to four times higher compressive strengths than samples from process B. Sludges treated by processes E and F had compressive strengths in the same range as low-strength concrete.

Sludge samples solidified using processes B and G have permeabilities resembling those of untreated sludges. Processes A and E decreased the sludge permeabilities to one one-hundredth the value for untreated sludges.

In general, freeze-thaw and wet-dry testing showed that the solidified materials had durability properties similar to soil-cement or low-strength concrete and only sludges solidified by process E held up to any degree, having all samples withstand wet-dry test cycles and half surviving freeze-thaw test cycles.

Physical and engineering tests indicate that solidification processes do not always alter the physical and engineering properties of the sludges in ways which would be expected to enhance their ability to contain noxious constituents. Testing procedures adapted specifically to sludges and solidified sludges might increase our ability to predict the success of solidification processes.

SECTION 6

RESULTS OF LEACH TESTING

PATTERNS OF SLUDGE CONSTITUENT LEACHING

The columns were designed and loaded to simulate the conditions that might be found in disposing of the sludge in a landfill or sludge disposal site. The sludge columns also approach those conditions operating in the leaching of homogeneous, fine-grained soil columns. Such soil columns have been widely studied in attempts to devise efficient systems for leaching salts from irrigated soils (15, 16). Phenomena observed in these soil experiments can also be related to the chemical composition of leachate from the sludge columns. Variables which have been found to be important to the rate of leaching loss of minerals from fine-grained soils are:

- a. Diffusion of materials in the solid phase.
- b. Capillary mixing (or hydrodynamic dispersion).
- c. Diffusion of ions in solution.
- d. Solution or precipitation of chemical constituents in the column.
- e. Absorption and desorption of ions on insoluble materials.
- f. Movement of suspended material out of the columns.
- g. Biological activity within the columns.
- h. Compaction of materials within the columns.
- i. Cementation of material in the columns.
- j. Channelization of fluid movement in the columns.

Combinations of these factors would also be expected to be determining the leaching performance of the columns in this study. Solid phase diffusion is probably not a limiting factor in the leaching of untreated sludges as it would be in the case of solidified sludges since the very fine-grained nature of untreated sludge causes rapid equilibration between the grain interior and exterior. Capillary mixing, ion diffusion, and solution and precipitation of the various components of the treated and untreated sludges are probably of major importance to the behavior of the materials in the columns.

Although variations in the concentrations of many constituents are quite apparent between columns and between samples collected from the same column, the bulk of the leaching data can be typified as fitting one of two or three relatively distinct leaching patterns. These patterns are illustrated by the data for calcium concentrations in leachate from the untreated sludge columns shown in Figure 13. The data are expressed as calcium concentration in the leachate versus the time of leaching in days. Leachate from untreated sludge 400R (and for 100R and 600R, not shown) maintains a nearly uniform calcium concentration throughout the time period shown. These columns ultimately produce leachates saturated with respect to calcium sulfate. This pattern of leaching would be expected for those compounds which are present in the sludge in large amounts compared to their solubility. This relatively constant leach rate (or concentration in leachate) would be expected to continue until the bulk of the material was lost from the column or the column channelizes. The amount of material leached in this case is a function of the total leachate volume and is not necessarily related to the leaching time.

The calcium leach data from column 500R illustrate the second most prevalent leaching pattern -- that of a high initial loss of a constituent followed by a rapid, apparently asymptotic drop to a low end value which then remains constant throughout the remainder of the leaching period. In the case of untreated sludge 500R, the low end value approaches the detection limits for this element. In samples taken early in the leaching program, the calcium concentration is near saturation for calcium sulfate but, either by channel formation (as is probably the case) or by exhaustion of the material from the sludge or treated sludge surface, the loss rate rapidly falls to a lower value as the constituent is washed out and depleted in the effective flow path. This same pattern of rapid depletion will be seen for very soluble constituents, such as chloride, and for some moderately soluble materials from the treated sludge columns.

The leaching pattern of calcium concentration from sludge column 100R shows a third leaching pattern (Figure 13) in which the initial concentration is low and rises slowly during the leaching period. For this column, the much lower concentration of calcium leached is believed to reflect the high levels of sodium remaining in these double alkali FGC sludges. The rising values may reflect the gradual depletion of the sodium in the column. This is supported by the very high values of sulfate leaching from this column as would be expected from the much higher solubility of sodium sulfate. This high concentration of sodium sulfate, which is presumed to be lost, must reduce the rate of dissolution of calcium. The low calcium concentration in leachate from the double alkali sludge is evident in both treated and untreated sludges.

The relative effects of solidification of the FGC sludges by the different processes is illustrated in Figure 14 which compares the leach rates of calcium from the treated and untreated sludge 100 columns. All of the treated sludge columns have lower overall leach rates than the untreated columns but two distinct leach patterns are observed. In columns 100A and 100F, the treatment has not reduced calcium concentration in the leachate to any great extent. The leachate concentrations from these columns are only slightly lower than the leachate concentration from untreated material and both tend to approach

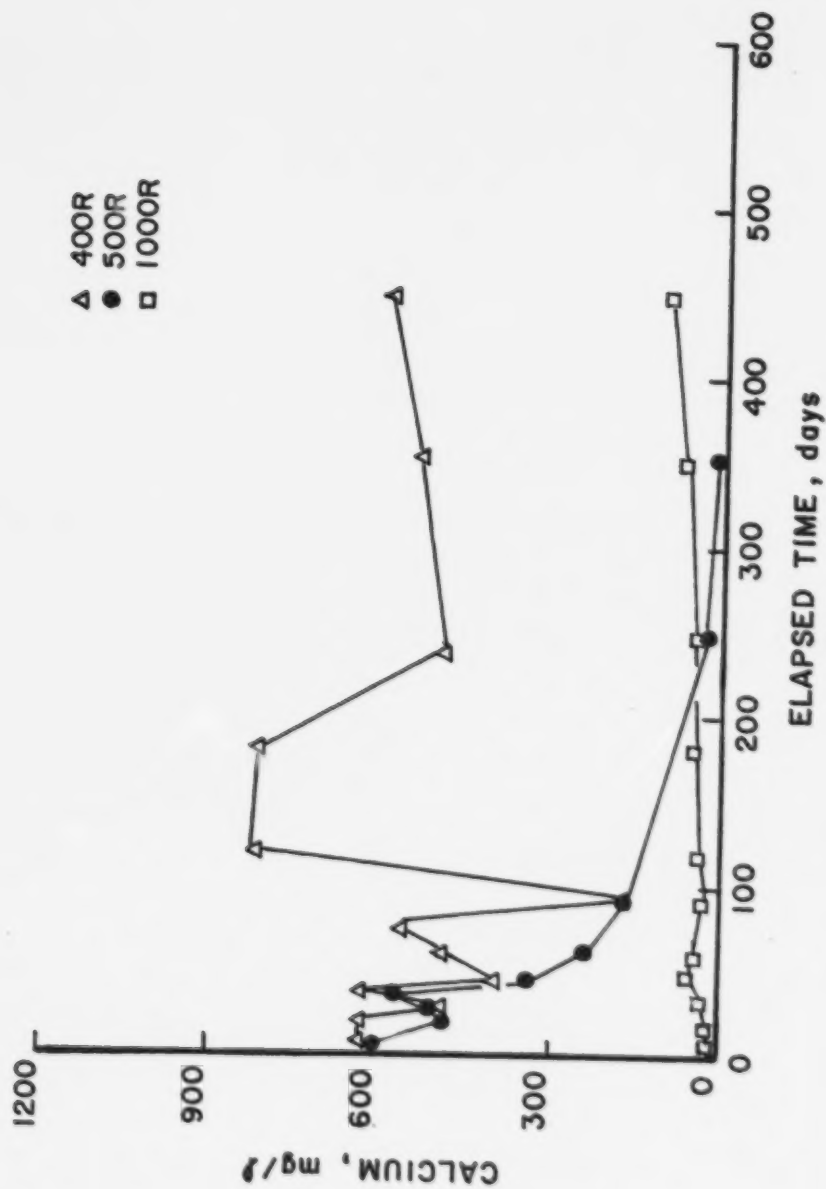


Figure 13. Concentration of calcium in leachate from untreated sludge columns.

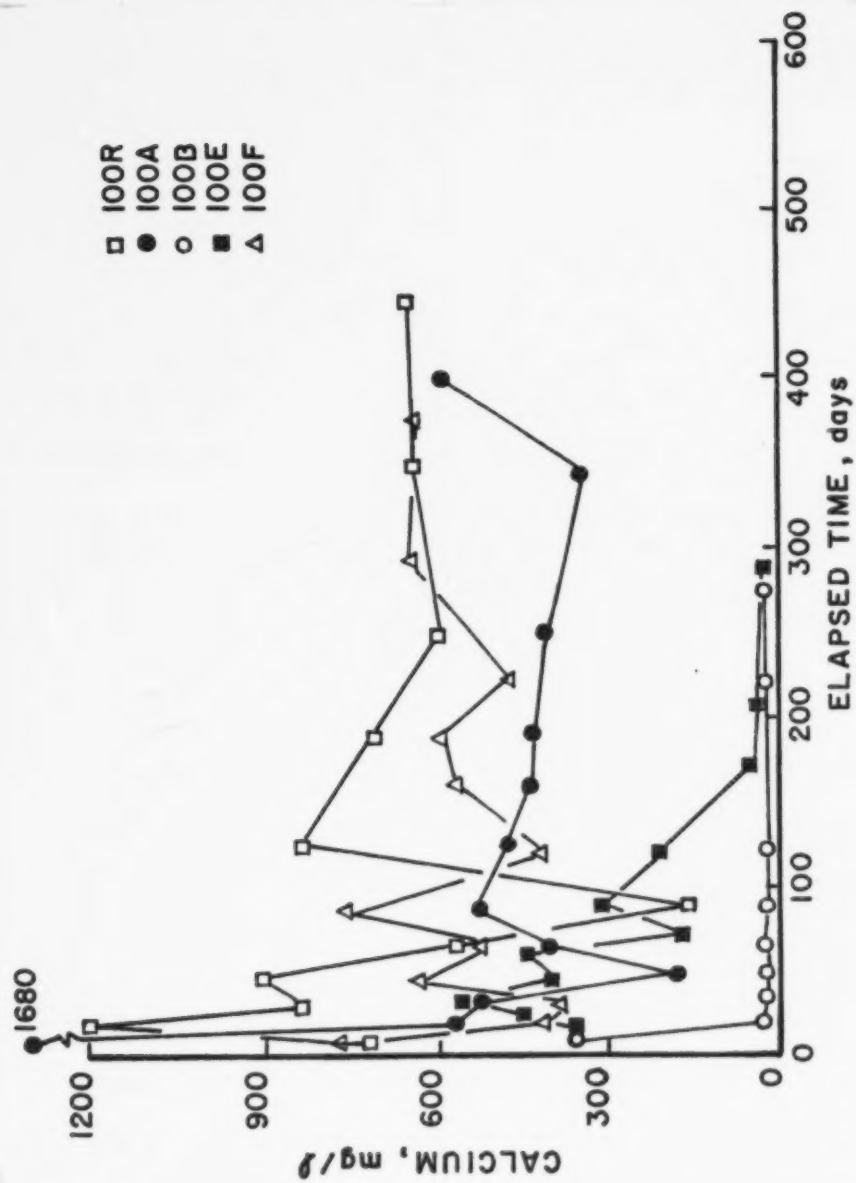


Figure 14. Calcium concentrations in leachate from treated and untreated lime process, eastern coal sludge (No. 100) columns.

the leach rate for untreated material over the long term. These solidification processes have not really had a major impact on calcium loss from this sludge.

Columns 100B and 100E, however, even though they have relatively high initial calcium concentrations in the leachate, appear to have stabilized the majority of the calcium in the sludge, since the concentrations of calcium in the leachate rapidly fall to near zero. In this pattern, the leachate concentration is initially very high, perhaps even saturated, but rapidly falls to a steady low value reflecting the lack of soluble calcium salts on the surface of the solidified waste.

These same general patterns are reflected in the sulfate leachate concentrations from these columns as shown in Figure 15. Again, although the overall concentrations of sulfate leached from columns 100A and 100F are lower than those from the column containing untreated material, they are appreciable and may even be increasing near the end of the experiment. Column 100B maintains a sulfate concentration which is consistently a third or less of the untreated column sulfate concentrations. Column 100E has little sulfate in its leachate at any time, although the concentration in the leachate is slowly increasing over the period of the experiment.

Constituents of the sludges which have solubilities much higher than their leachate concentrations in the columns also exhibit leaching patterns similar to those seen for calcium in columns 100B and 100E. These are illustrated for chloride in Figure 16. In this data plot, the first two or three samples contain the highest concentrations, but the concentration falls asymptotically to levels below detection limits soon after leaching begins as the available soluble material is lost from the column. The greatest proportions of these constituents are lost to leaching waters in the early part of the leaching regime.

This leaching pattern is also seen in columns containing inert materials such as glass beads with a salt solution in the pore space (17); the leachate shows a rapid decrease in salt concentration as the nonsaline leaching fluid mixes with and displaces the saline pore solution. The rate of decrease in concentration of salt in the leachate is related to the velocity of the fluid and the size and directness of pore connections. The incoming leaching solution does not perform a piston-like displacement of the pore water, but rather mixes with the interstitial water. This property of a packed column is called "hold back." Coarse sands with minimum pore volume have the least hold back; clay-sized materials have the greatest. Therefore, the tailing off of solution concentration would be expected to be greatest with the untreated sludges and least pronounced in the pellet-packed stabilized columns.

A second representation of this calcium ion data in which accumulated mass of the constituent leached is plotted against leaching time is shown in Figure 17. This presentation clearly indicates the rapid depletion of the leachable calcium in columns 100B and 100E. However, the geometric spacing of the sampling times used in this study (and the unequal sample volumes and sampling intervals) causes the typical curves for columns 100R, 100A, and 100F to be nonlinear. Linear plots for constant-concentration leaching patterns would

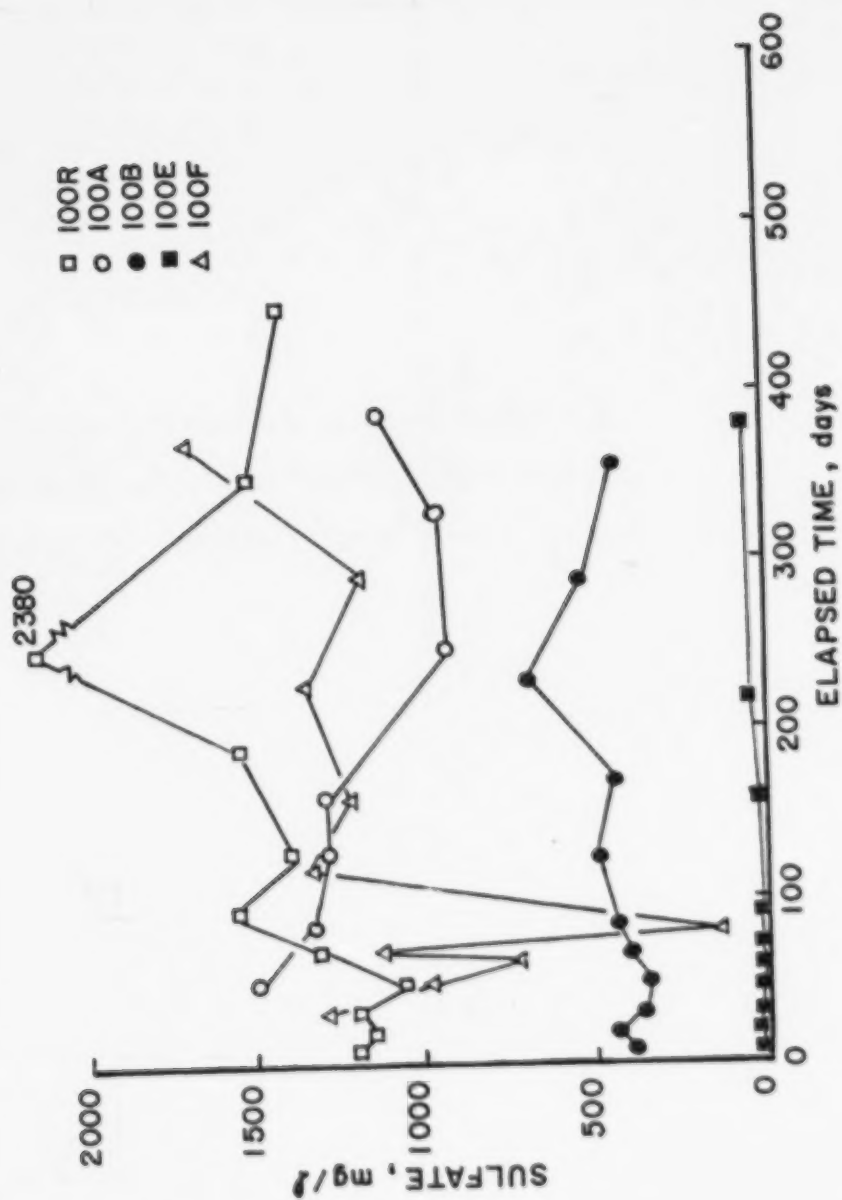


Figure 15. Sulfate concentrations in leachate from treated and untreated lime process, eastern coal sludge (No. 100) columns.

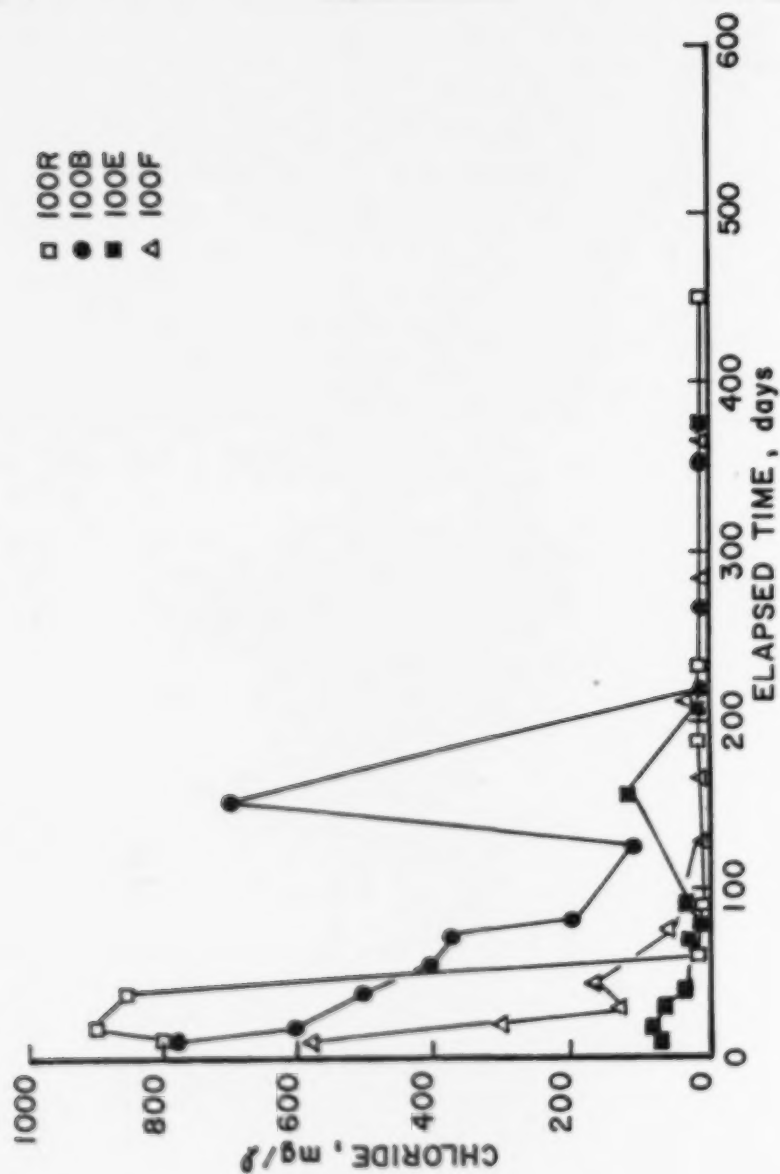


Figure 16. Chloride concentrations in leachate from treated and untreated lime process, eastern coal sludge (No. 100) columns.

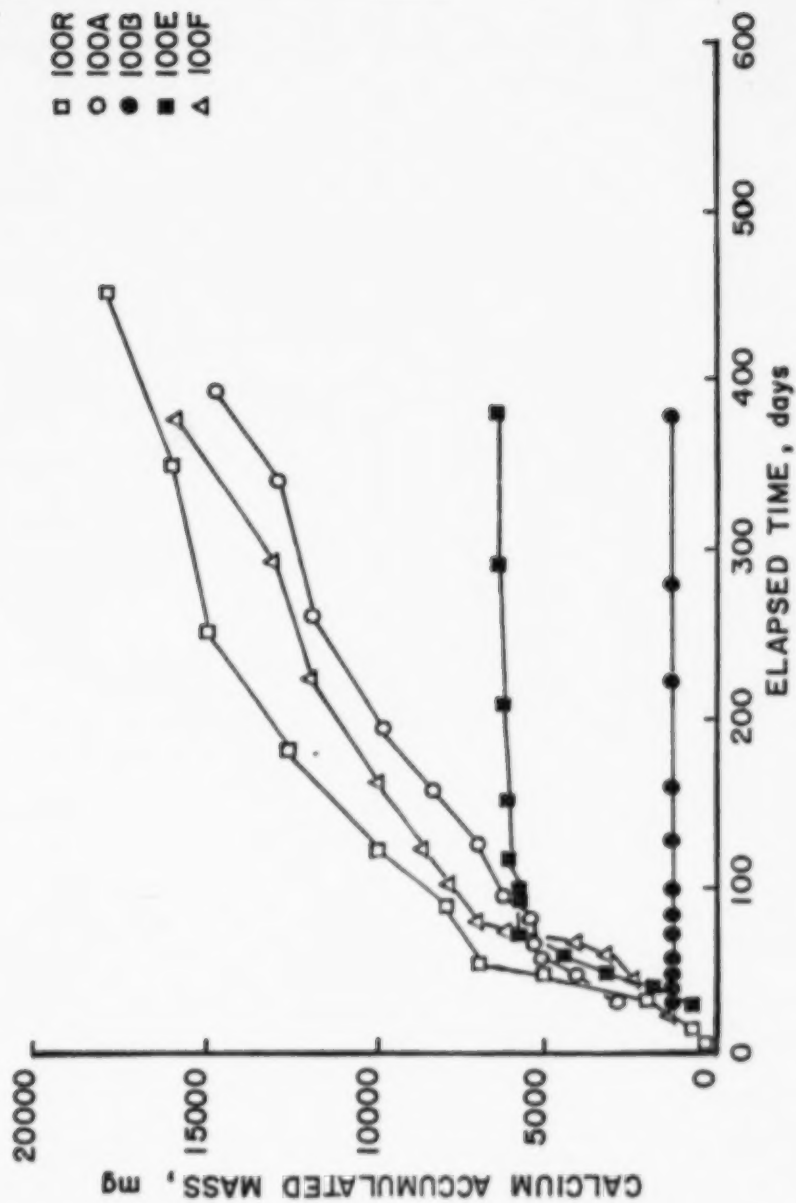


Figure 17. Accumulated mass of calcium leached from treated and untreated lime process, eastern coal (No. 100) columns as function of leaching time.

occur only if the leaching rate is precisely controlled so that equal rates (volume/day) of leachate occurred throughout the duration of the experiment.

Although an attempt was made to obtain equal flow rates from the columns in this study, wide variations in flow rate between columns were experienced because of differences in the physical properties of the treated and untreated sludges and a tendency for the column ports and valves to clog. For individual columns, flow rates were generally higher (up to 4.5 liters/week) during the early 7-day sampling periods. The columns were freer flowing early in the study. No more than 4.5 liters of leachate was produced in the 108 days of the last sampling period (maximum average weekly flow rate of 0.29 liters/week). Under this sampling regime, higher constituent loss-rates are apparent at earlier (shorter) sampling periods, but this only reflects the variable sampling frequency.

This decrease in flow rates was especially evident in several of the untreated sludge columns. The columns apparently became compacted and cemented (i.e., material was being deposited between the sludge particles in the column). Some cementation was expected since the columns were leached with water saturated with carbon dioxide.

A method of data presentation which compensates for the unequal sampling time and flow rates is shown in Figure 18, in which the accumulated mass of the leached constituent (calcium) is plotted against the accumulated leachate volume. Curves for 100B and 100E retain their asymptotic approach to a constant maximum mass leached. Curves for 100R, 100A and 100F are now linear, as one would expect for samples which contained nearly the same concentration of the constituent measured (in this case calcium). Any samples having constant concentrations will give linear plots in this presentation irregardless of sample-size variations and/or fluctuations in flow rates. In spite of the variations that were present in the data for these last columns, the overall loss per unit volume is seen to be consistent as their curves can be approximated by a straight line. Similar linear leach rates of such major constituents would be expected for time periods much longer than those covered by this study.

Erratic patterns as illustrated by data in these figures, and others not presented, could result from a variety of factors and usually indicate lack of optimum leaching test conditions such as occurrence of channeling or non-uniform compaction. Other patterns, such as low initial leaching rates followed by increasing leach rates, may be typical of constituents which become more soluble during the leaching period. Seemingly random occurrences of high concentrations of constituents in the leachate may follow the production of new fractures, channels, or flow patterns which expose previously isolated portions of the sample. Channels would be expected to produce quite variable leachate concentrations as the leachate composition is related to the effective amount of surface area between the leachate and the sludge.

Several factors within the sludge crystals or particles, or from interactions of the sludge solids and the leaching fluid, will cause modification of the leaching patterns. At the low flow rates used in this study, ionic diffusion becomes significant in the movement within the column (17). The

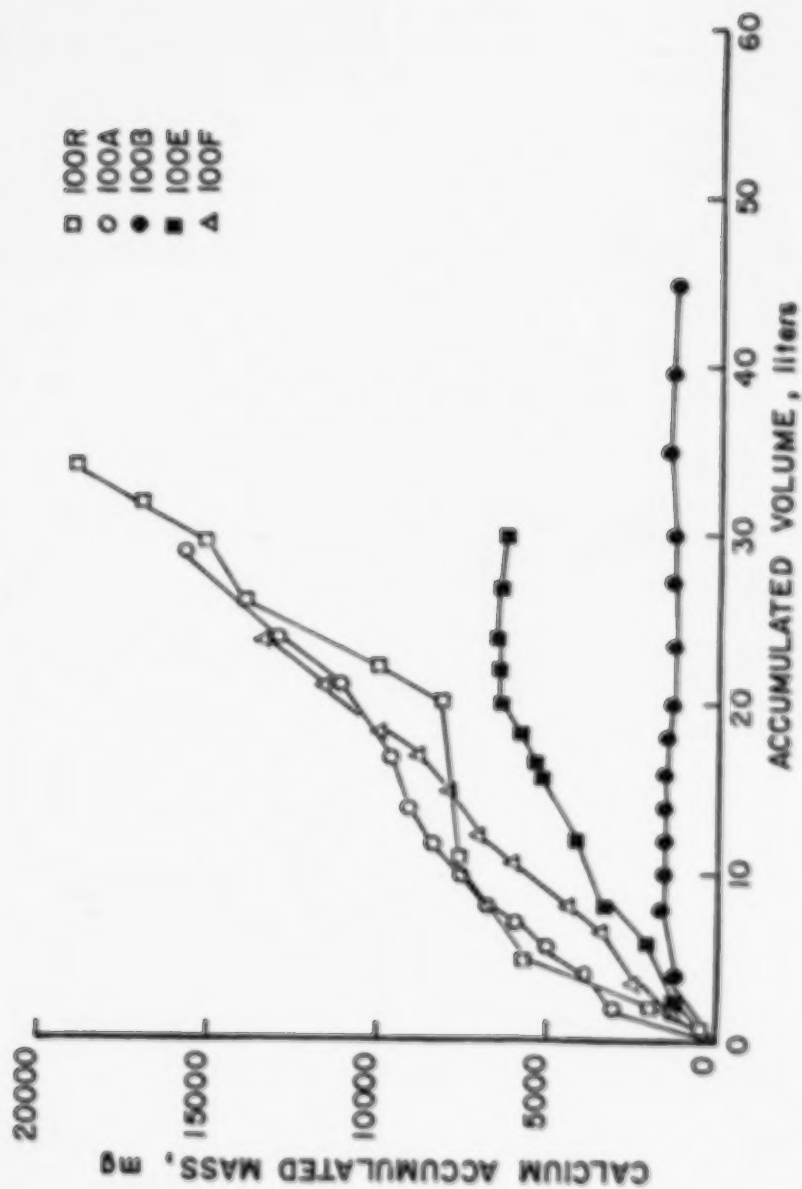


Figure 18. Accumulated mass of calcium leached from treated and untreated line process, eastern coal (No. 100) columns as a function of accumulated leachate volume.

apparent effect of the incoming leaching fluid will occur at an earlier time than flow prediction alone would indicate because ionic diffusion is faster than the movement of the fluid front. As the leaching fluid moves through the sludge column, the composition of the liquid changes and comes into chemical equilibrium with the material in the column. The column leaches from the top down with the most soluble materials being leached most rapidly. The chlorides of alkali metals and alkali earths are the first materials leaving most columns. The carbonates react with the carbon dioxide in solution (carbonic acid, H_2CO_3) and are effectively leached as more soluble bicarbonates at rates dependent upon the availability of carbon dioxide. Precipitation of material within the columns can occur as new equilibria are established at different levels in the columns.

The columns can behave as an ion exchange or chromatographic system. The leaching can theoretically proceed in fronts or pulses reflecting difference between the solutions in equilibrium with the different levels of the columns or the incoming leaching fluid. The leaching constituents would be separated on the columns on the basis of their adsorption characteristics on the solid or supporting materials in the column (18).

The leach test columns used in this study were designed to simulate field conditions where the pollution potential includes not only materials dissolved in the leaching solution, but also any suspended materials which might be carried along with it. Fine material did escape from the columns and move into the collection vessels where it settled to the bottom for the duration of the sampling period. The character of the fine material (density and grain size), as well as the length of the sampling period and method of treatment for sample preparation, effected the actual amount of any constituent measured. Short term experiments conducted with sludge 600R (untreated lime process, western coal) indicate that suspended materials could account for a major portion of the metal load (up to 75 percent) observed in the unfiltered samples as analyzed in this study.

UNTREATED FGC SLUDGE COMPOSITION

The flue gas cleaning (FGC) sludges are representative of the three major nonregenerative flue gas treatment system and are from plants burning eastern or western coal. The results of analysis of the five untreated FGC sludges for selected constituents are given in Table 16. The sludges were dried, weighed, and digested in hot 8N nitric acid and analyzed. The constituents included in the analyses make up from 60-85 percent of total mass of dried sludge in all cases except in the case of sludge 600, the lime process western coal. The digestion process would take the FGC sludge products in solution and leave behind the coal dust, ash and other siliceous materials in the FGC mixture. The sample of sludge from the lime process for western coal (No. 600R) appears to be anomalous in several ways. It is lower in calcium and sulfate and higher in iron than other sludges. The sludge liquor also has an unusually low pH. The low percent recovery is probably due to the presence of a large amount of fly ash and coal dust in this particular sludge.

The major constituents of all the FGC sludges are calcium and sulfate or

TABLE 16.

TABLE 16. ANALYSIS OF UNTREATED FLUE GAS CLEANING SLUDGES

Constituent	Mg/Kg in Dry Sludge Solids					Average All Sludges
	Lime Process Eastern Coal (100)	Limestone Process Eastern Coal (400)	Double Alkali Eastern Coal (500)	Lime Process Western Coal (600)	Double Alkali Western Coal (1000)	
As	37	14	46	19	BDL	23
Be	12	6.9	7.3	10	6.3	8.5
Ca	299000	286000	283000	118000	283000	235600
Cd	73	54	75	73	58	66.5
Cr	167	118	119	111	91	121
Cu	52	61	52	53	16	47
Fe	39500	9970	11200	20700	3150	14800
Hg	3570	4420	4440	5040	1940	3880
Mn	125	79	143	178	59	117
Ni	100	86	85	67	50	77
Pb	13	7.4	27	38	43	26
Zn	144	117	209	127	57	131
Cl	56400	19600	63000	29400	19400	37500
SO ₄	206800	378100	247000	110500	546000	297000
% Recovery	60%	70%	61%	28%	85%	61%
Sludge Liquor pH	10.3	10.0	13.1	7.5	12.7	10.7

BDL = below detection limits.

sulfite (all sulfite present has been oxidized to sulfate during digestion) which make up between 50-80 percent of the digestible dry sludge solids. Chloride is also present at levels between 2 and 6 percent. Of the metals, iron and magnesium are highest in amount, with levels between 0.2 and 2 percent of dry sludge solids. Chromium, manganese and zinc are typically present at lower levels (averaging near 100 mg/kg dry sludge solids). Arsenic, beryllium, cadmium, copper, nickel and lead are all present in amounts less than 100 mg/kg dry sludge solids.

The FGC sludge samples used in this study have compositions typical of those reported in previous studies (4, 8). Most constituents are present in similar concentrations in all of the sludges; e.g., cadmium at 60-75 mg/kg, magnesium at 2000-5000 mg/kg, nickel at 50-100 mg/kg, calcium at about 28 percent. A few constituents, such as iron, lead, zinc, and chloride, and sulfates, show rather wide variations which may reflect differences in scrubbing additives or composition of the coal. The FGC sludges produced from western coals generally have lower heavy metal concentrations (except for lead) and nearly equal concentrations of manganese when compared to FGC sludges from eastern coals. This difference has been reported elsewhere (4). The average composition of all the FGC sludges used in this study is given in Table 16. Only beryllium is present at less than 10 mg/kg (dry wt.) on the average. All of the toxic metals (cadmium, chromium, copper, lead, and zinc) included in the analyses were present in large enough quantities to cause concern as to their mobility in any disposal operation.

CONSTITUENT LOSS FROM UNTREATED SLUDGE COLUMNS

An average of 6.95 kg of untreated FGC sludge was placed in each of the leaching columns. The sludges were well-mixed and poured into the columns. Over a period of time, the sludge solids settled and compacted into the lower portion of the column. The compacted sludge greatly decreased the rate of flow of leaching fluid through the column as is evident in the average flow rate per sampling time as seen in Table 17. The irregular flow patterns and leachate composition variations found were apparently related to the development and shifting of flow channels within the compacting untreated sludge.

Direct evidence of channelization was found by adding dye to the leaching solution and watching its progress through the columns after the regular leaching experiments had been terminated. The columns dye-tested had been set up for 26 months. Fluorocene and rhodamine dyes were added to the leaching solution and their progress was monitored. Most channels appeared to be internal to the sludge (not between the sludge and the column wall) as pockets of the dye would progressively appear down the length of the column. When the dyes first became visible in the leachate, none of the untreated FGC columns tested showed any uniformity of dye distribution in the column and the dye arrived at the bottom of the column far ahead of the theoretical transit time. This compaction and channelization phenomena in the untreated sludge are important to the analysis of the leaching data for the untreated FGC sludge columns and the comparison of these data with the data from the fixed sludge columns. The net result of these two processes has the effect of partial solidification of the sludge. The solidified sludges are essentially similar

TABLE 17. LEACHATE VOLUMES COLLECTED FROM PRIORITY, UNTREATED SLUDGE COLUMNS

Sampling Day	Collection Interval (Days)	Sludge No. 100 Vol(t) t/Day	Sludge No. 400 Vol(t) t/Day	Sludge No. 500 Vol(t) t/Day	Sludge No. 600 Vol(t) t/Day	Sludge No. 1000 Vol(t) t/Day
1	1	0.12	0.67	0.60	0.14	1.86
8	7	0.34	0.50	0.89	2.50	4.5
14	6	2.44	2.82	0.48	3.80	4.5
21	7	3.15	1.41	0.45	1.60	3.25
28	7	1.60	3.73	0.40	3.32	3.10
39	11	4.5	3.32	0.31	4.5	3.32
63	24	3.80	3.34	0.31	2.68	2.44
91	28	3.55	3.71	1.29	4.5	2.58
126	35	2.38	2.03	0.57	0.14	4.10
189	63	4.5	3.38	ND	ND	4.5
245	56	2.65	4.5	3.42	4.5	2.65
353	108	2.38	3.40	1.86	3.41	3.24
451	98	2.29	ND	ND	1.69	4.5
569	118	1.34	2.55	ND	2.12	2.03
708	139	4.5	1.94	1.86	2.20	4.5
814	106	4.5	4.5	ND	1.51	4.5
TOTAL	(814)	44.04	40.82	12.45	38.68	55.57
		(0.054)	(0.050)	(0.015)	(0.047)	(0.068)

Note: Samples collected until 4.5 t had accumulated, at which time the flow was stopped.
ND = Not Determined.

to channelized untreated material in that the leaching liquid comes in contact with only a small part of the material in the column. The solidified sludges could actually present a larger effective surface area to the leaching medium than a severely channelized and compacted, but untreated, sludge.

A summary of the column leaching data from the priority columns containing the untreated FGC sludges is presented in Table 18. Two parameters, the overall, or average, concentration, and the highest concentration are given in the table for each constituent analyzed. The overall concentration of the constituent is calculated as the total weight of the constituent leached divided by the total volume of leachate collected from the column--i.e., the overall concentration of the constituent had all of the leachate been pooled and analyzed. This number represents the approximate concentration of the constituent which might be expected under a variety of leaching circumstances. The second parameter--the highest concentration of the constituent ever found in any single leachate sample--represents the worst case found in this study.

The constituents leached in the greatest amounts from the untreated sludge columns are calcium, sulfate and chloride. The leachate from lime and lime-stone process sludges has a consistent level of calcium (500 mg/l average and 750-1200 mg/l highest concentrations) and sulfate (1000-1500 mg/l average with highest concentrations found between 2000 and 3000 mg/l). The average concentration figures are very close to that of a saturated aqueous solution of calcium sulfate--gypsum (600 mg/l calcium and 1480 mg/l sulfate). The leachate from these columns is saturated with calcium sulfate and would be expected to remain so until the bulk of the sludge had been leached away.

The untreated double alkali sludge columns produce a leachate which is typically lower in calcium (80-150 mg/l average) but with much higher amounts of sulfate (3000-14000 mg/l average). Leachate which has 3-4 percent sulfate is found from both double alkali sludge columns. These extremely high concentrations of sulfate represent a difficult problem associated with disposal of these sludges--a small amount of leachate from these wastes would degrade a much larger quantity of groundwater. The high sulfate (and low calcium) values are a reflection of the high levels of sodium which are associated with the double alkali sludges. Even after the complete loss of monovalent cations from these sludges, the leachate would be expected to come into equilibrium with the undissolved calcium sulfate in the sludge, as do the other FGC leachates. This was observed to happen in sludge 1000R.

Chloride, although present in approximately equal amounts in all sludges (2-6 percent by weight), is leached most readily from the FGC sludges associated with western coal and exceeds drinking water standards (on the average) only in these leachates. Chloride from the FGC sludge leachate does not seem to present a continuing pollution threat. Chloride generally has very high concentrations in the first few sampling periods, but these levels rapidly drop as the readily available chloride is leached out (Figure 16).

Of the other constituents analyzed, three (arsenic, chromium and manganese) are found to average near, or higher than, drinking water standards in all samples of leachate from all FGC sludges. Average levels of arsenic and chromium are found to be near the drinking water standards, but varying

TABLE 18. CONCENTRATION OF SELECTED CONSTITUENTS IN LEACHATE FROM THE PRIORITY, UNTREATED FCC SLUDGE COLUMNS

Constituent	Lime Process			Limestone Process			Double Alkali			Lime Process			Double Alkali			Average			Drinking Water Standards (mg/l)
	Overall	Highest	Eastern Coal (100)	Overall	Highest	Eastern Coal (400)	Overall	Highest	Eastern Coal (500)	Overall	Highest	Western Coal (600)	Overall	Highest	Western Coal (1000)	Overall	Highest	Western Coal (1000)	
As	0.029	0.112	0.004	0.009	0.009	0.009	0.169	0.667	0.667	0.002	0.004	0.004	0.027	0.016	0.016	0.046	0.667	0.667	0.050
Be	0.004	0.080	0.007	0.041	0.041	0.041	0.005	0.006	0.006	0.018	0.142	0.142	0.005	0.039	0.039	0.007	0.142	0.142	--
Ca	475.	1220.	481.	777.	777.	777.	148.	589.	589.	483.	749.	749.	88.7	101.	101.	335.	1220.	1220.	--
Cd	0.0004	0.001	0.001	0.009	0.009	0.009	0.010	0.032	0.032	0.009	0.070	0.070	0.006	1.030	1.030	0.005	1.030	1.030	0.010
Cr	0.025	6.199	0.004	0.036	0.036	0.036	0.217	1.499	1.499	0.070	0.999	0.999	0.009	0.016	0.016	0.065	6.199	6.199	0.050
Cu	0.003	0.280	0.014	0.126	0.126	0.126	0.055	0.299	0.299	0.014	0.090	0.090	0.051	0.140	0.140	0.027	0.299	0.299	1.00
Hg	1.570	40.97	1.080	2.740	2.740	2.740	0.200	0.640	0.640	26.300	310.0	310.0	0.519	2.140	2.140	5.934	310.0	310.0	--
Mn	0.008	1.420	0.004	0.004	0.004	0.004	0.033	0.082	0.082	1.960	13.00	13.00	0.005	0.014	0.014	0.402	13.00	13.00	0.050
NI	0.041	0.500	0.139	0.753	0.753	0.753	0.326	2.400	2.400	0.214	1.290	1.290	0.025	0.351	0.351	0.745	2.400	2.400	--
Pb	0.001	0.110	0.001	0.014	0.014	0.014	0.084	0.999	0.999	0.033	0.056	0.056	0.065	1.000	1.000	0.013	0.999	0.999	0.050
Se	--	0.023	0.006	0.027	0.027	0.027	0.121	0.690	0.690	0.289	2.900	2.900	0.026	0.067	0.067	0.110	2.900	2.900	0.010
Zn	0.006	0.920	0.012	0.042	0.042	0.042	0.024	0.068	0.068	0.040	0.290	0.290	0.003	0.020	0.020	0.017	0.920	0.920	5.0
Cl	130.	963.	17.	158.	158.	158.	12.4	25.	25.	331.	2173.	2173.	379.	3531.	3531.	196.	3531.	3531.	250.
Cn	--	0.09	0.01	0.10	0.10	0.10	--	0.07	0.07	--	0.09	0.09	--	0.07	0.07	--	0.100	0.100	--
SO ₄	1030.	2390	1410.	1900.	1900.	1900.	14950.	34000.	34000.	1500.	2940.	2940.	3200.	39900.	39900.	4420.	39900.	39900.	250.
SO ₃	--	3.	0.62	2.	2.	2.	--	575.	575.	--	20.	20.	--	2805.	2805.	--	2805.	2805.	--

* From Reference 19.

NOTE: (--) = too few data for meaningful calculation. Overall calculated as total mg leached/total volume leachate collected; highest is highest concentration of that constituent found in any individual sample.

widely between leachates from the different untreated FGC sludges. Manganese levels are variable in leachates from different sludges, but remarkably high concentrations (up to 13 mg/l) occurred in leachate from sludge 600R. The low pH of this sludge may cause more of the manganese to go into solution in this sludge than in other, more alkaline sludges.

Selenium also appears to be a potential problem. Average concentrations of over 0.100 mg/l occur in leachates from two of the FGC sludge types. This is ten times the drinking water standard. Very high values again are found in the lime process, eastern coal FGC sludge column (600R) with the anomalously low pH value.

The average leach rates of all other constituents are well below levels which might cause concern. However, several constituents were found in high concentrations in individual leachate samples. Cadmium exceeded drinking water standards in at least one sample from three untreated sludge columns. High chromium levels (above drinking water standards) occurred in two leachate samples. High lead concentrations occurred in four samples. Of the toxic constituents studied, only beryllium, copper, zinc, and cyanide were never found at potentially dangerous levels in leachate from any untreated sludge.

Comparison of the leaching rates of the five untreated FGC sludges indicates that the potential contaminant loss from the five sludges is nearly the same, even though relatively large differences in leach rates for several constituents occurred among the sludges. The highest single levels of all constituents are distributed relatively evenly between the five sludge columns--double alkali have 50 percent and lime and limestone processes have 50 percent of the highest levels found; likewise eastern and western coals each share 50 percent of the highest individual concentrations. The highest overall concentrations of escaping materials are shared by the eastern coal, double alkali column (500R) and the western coal, lime process column (600R). The limestone process, eastern coal had the fewest average and individual highest concentration levels, but appears to present nearly the same potential contamination problems as all other sludges.

The percent of selected constituents removed from each untreated FGC sludge column during leaching is compiled in Table 19. This data compilation compensates for differences in column sludge loading. The median value for the percent lost for each constituent in all five columns is shown on the right of the table. Less than 1 percent of most constituents was lost over the length of the study. Exceptions to this observation are sulfate and chloride. Between 2 and 10 percent of the sulfate present was lost (median = 4.87 percent) from each column. The percent chloride lost was variable, but the median for all five columns was over 1 percent. There is a good relative agreement between this presentation of the data and that of the previous table (Table 18) as would be expected, because all untreated sludge columns contained nearly the same amount of sludge. These experimental leaching procedures were more severe than would be found in nature. On the average, 40 to 50 liters of leaching medium passed through each column in the 2 years of the study. Forty liters of water applied to the 10.2-cm-diameter columns is equivalent to about 500 cm of infiltration over the 2-year experimental period. Assuming 50 percent infiltration, this rate of application is equivalent to

TABLE 19. PERCENT OF SELECTED CONSTITUENTS LEACHED FROM PRIORITY, UNTREATED FGC SLUDGE COLUMNS OVER ENTIRE STUDY

Constituent	Lime Process Eastern Coal (100)	Limestone Process Eastern Coal (400)	Double Alkali Eastern Coal (500)	Lime Process Western Coal (600)	Double Alkali Western Coal (100)	Median Value
As	0.465	0.149	0.642	0.056	BDL*	0.149
Be	0.214	0.612	0.014	0.937	0.671	0.612
Ca	0.935	0.971	0.093	2.13	0.259	0.935
Cd	0.003	0.012	0.024	0.062	0.318	0.024
Cr	0.088	0.022	0.323	0.332	0.054	0.088
Cu	0.036	0.130	0.190	0.137	0.452	0.137
Mg	0.260	0.141	0.008	2.72	0.221	0.221
Mn	0.039	0.027	0.041	5.74	0.071	0.041
NI	0.244	0.932	0.677	1.66	1.09	0.932
Pb	0.055	0.094	0.563	0.453	0.978	0.453
Zn	0.026	0.060	0.020	0.162	0.042	0.042
Cl	1.36	0.510	0.348	5.87	16.2	1.36
SO ₄	2.93	2.15	10.7	7.07	4.87	4.87

* BDL = Below Detection Limits

500 cm of precipitation (about 200 in.) per year. Even at these high loss rates, the sludge constituents would continue to be leached from a typical disposal area for decades.

CONSTITUENT LOSS FROM TREATED SLUDGE COLUMNS

To aid in data interpretation, three presentations have been prepared which address three different facets of the potential for pollution from the fixed sludges. The overall leachate concentration summary presents the concentration of the constituent under consideration as if all of the leachate were pooled and analyzed at one time. These data give "average" leachate concentration throughout the duration of the experiment. A second aspect of the data is presented by listing the highest concentration of each constituent found throughout the experiment. This is the worst case value and gives an estimate of the maximum concentrations of the constituent which might be encountered in leachate. As this represents a single value, a wide variation can be anticipated.

A comparison of the leach rates from these columns containing sludges solidified by different processors with the leachate from the corresponding untreated sludge columns is also presented. In this data presentation, the five FGC sludges are treated as replicates and the averages and the highest values are compared with the sample parameters from the untreated sludge columns. The comparison is presented in two ways--a simple "H" or "L" if the treated column leachate value is higher or lower than the untreated (control) column, respectively, and a T/U ratio which is simply the concentration of a particular constituent in the leachate from the treated column divided by the corresponding value for the leachate from the untreated column. The T/U ratio gives a quantitative measure of the "H" or "L" relationship in the table.

The third presentation, the percent of the constituents leached from the columns, is calculated by accumulating the actual mass (concentration volume leached) of each constituent lost over the total experiment. These masses leached are then presented as a percentage of each constituent originally loaded into the column in the sludge. Any materials which might have been added in the processing are not included in the calculation, so that losses of over 100 percent are possible. This calculation takes into account the wide variations in the amount of dry sludge solids prepared and loaded into the columns (Table 3). Most solidified sludge columns contain approximately one-half as much dry sludge solids as do the untreated columns. Part of this difference in amount of sludge placed in the treated sludge columns is accounted for by the space taken up by the polypropylene beads. It should also be noted that some treated material had less than 20 percent of the dry sludge solids in the untreated sludge columns. An approach similar to that used with the average and highest concentration data is also given. The percent leached from the solidified material is compared to the percent leached from the untreated material using a simple ratio (T/U).

Process A uses fly ash and a lime additive to produce a pozzolan product which sets into a monolithic mass. The overall leachate concentration and highest concentration found in leachate from columns containing sludges

stabilized by process A are compiled in Table 20. The loss of pollutants from the treated sludges is seen to follow the same patterns as their loss from the untreated sludges as previously described. Calcium and sulfate are lost in relatively large amounts from all sludges. Magnesium and chloride are also lost in appreciable amounts. Calcium, as in the untreated material, is much lower in the leachates from the double alkali columns although the sulfate levels are approximately the same from all sludges. The leachate pH values for the double alkali sludges are higher in the treated column leachate samples than they were in the untreated material.

The treated sludge columns are lower for ten constituents for which comparisons are made in the average concentration in the leachate (Table 21). Beryllium, manganese, nickel, selenium, zinc, chloride, and sulfate are held to less than one-fifth the concentration in the leachate from the untreated sludges. Calcium, chromium, and magnesium, although lower than their respective controls, are only 12 percent, 42 percent, and 58 percent lower overall. Arsenic, cadmium, copper, and lead had higher average concentrations in leachate from the solidified sludge columns than from the untreated sludge columns. The higher toxic metals levels may indicate contamination from the fly ash additive.

The same kind of analysis can be made for the comparison of the highest values of each constituent found. Arsenic, calcium, copper, and lead had higher worst case values in treated than in untreated leachate samples. This is four parameters out of sixteen tested. The agreement between the two kinds of data treatment is very good. Calcium, for instance, is 12 percent lower in overall leachate concentration, and 38 percent higher in the highest concentration--solidification by process A does not have a large effect upon its rate of loss, as measured by average or "worst case."

The percentages of each constituent leached from each treated sludge column and its relationship to the same untreated sludge column losses are presented for process A in Table 22. Since these calculations take into account the lesser amount of sludge in the solidified sludge columns, the number of constituents for which the solidified sludge column loses less material than the untreated sludge column is considerably lower. In fact, only 44-46 percent of the constituents measured are found to be leached at lower rates than in the untreated controls. The double alkali sludges (28 percent lower) appear to be less effectively stabilized than the lime sludges (58 percent lower) and the limestone sludges (46 percent lower).

Process B, which uses two additives to develop a product with a soil-like consistency, produces fixed sludges which have lower average leachate concentrations for all constituents except lead. Calcium levels are about one-fourth and sulfate levels about one-third those of the untreated sludges (Table 23). All heavy metals except lead and zinc are less than one-fourth of the untreated sludge leachate levels. Both zinc and chloride levels were essentially unchanged from their concentrations in untreated sludge leachate. For the stabilized sludge leachate, the highest concentration of each constituent is below that of the corresponding constituent from the untreated sludge leachate except in the cases of calcium and cyanide which are only slightly above the

TABLE 20. CONCENTRATION OF SELECTED CONSTITUENTS IN LEACHATE FROM PRIORITY COLUMNS CONTAINING SLUDGE TREATED BY PROCESS A

Constituent	Lime Process Eastern Coal Sludge 100		Limestone Process Eastern Coal Sludge 400		Double Alkali Eastern Coal Sludge 500		Lime Process Western Coal Sludge 600		Double Alkali Western Coal Sludge 1000	
	Overall	Highest	Overall	Highest	Overall	Highest	Overall	Highest	Overall	Highest
As	0.033	0.080	0.027	0.075	0.0345	1.700	0.010	0.033	0.015	0.110
Be	0.001	0.008	0.001	0.004	0.002	0.008	0.001	0.003	0.001	0.006
Ca	516.1	1680.0	413.6	783.0	45.21	128.3	428.6	760.0	70.62	235.0
Cd	0.021	0.198	0.065	0.440	0.054	0.164	0.023	0.173	0.036	0.400
Cr	0.012	0.037	0.021	0.111	0.018	0.089	0.023	0.094	0.021	0.179
Cu	0.077	0.486	0.009	0.083	0.056	0.294	0.014	0.084	0.058	0.097
Hg	5.146	10.570	3.660	8.370	0.533	5.320	2.726	4.970	0.390	1.850
Mn	0.001	0.003	0.076	1.422	0.007	0.074	0.112	1.522	0.105	2.722
Ni	0.008	0.030	0.008	0.038	0.035	0.258	0.024	0.200	0.025	0.385
Pb	0.011	0.048	0.005	0.034	0.043	0.400	0.061	0.800	0.067	1.200
Se	*	0.035	0.005	0.037	0.015	0.182	0.012	0.092	0.010	0.163
Zn	0.004	0.010	0.008	0.020	0.004	0.008	0.009	0.050	0.033	0.423
Cl	9.859	40.0	4.086	21.0	51.016	344.	7.071	42.0	3.802	47.0
CN	--	0.280	0.008	0.060	--	0.32	--	0.06	--	0.04
SO ₄	737.6	1500.	995.1	1900.	843.0	3091.	767.9	1650.	542.2	2450.
SO ₃	--	3.0	0.865	8.0	197.0	1395.	--	7.0	--	60.
Average pH	--	8.38	8.09		9.95		8.83		--	9.81

* Below 1 microgram/liter.

a. In mg/l, overall is total mg leached/total volume leachate collected; highest is highest concentration found in any individual sample.

TABLE 21. AVERAGE AND HIGHEST INDIVIDUAL CONCENTRATION OF CONSTITUENTS IN LEACHATE FROM ALL PRIORITY SLUDGE COLUMNS TREATED BY PROCESS A, AS COMPARED TO UNTREATED CONTROL COLUMNS

Constituent	Average Overall	Highest of all	Relative to Untreated Columns*			
			Average Overall	Highest	Average Overall T/U	Highest T/U
As	0.047	1.700	H	H	1.02	2.54
Be	0.001	0.008	L	L	0.14	0.05
Ca	294.8	1680.	L	H	0.88	1.38
Cd	0.040	0.440	H	L	8.00	0.43
Cr	0.038	0.179	L	L	0.58	0.03
Cu	0.043	0.488	H	H	1.59	1.63
Mg	2.490	10.570	L	L	0.42	0.03
Mn	0.060	2.722	L	L	0.15	0.21
Ni	0.020	0.385	L	L	0.03	0.16
Pb	0.037	1.200	H	H	2.84	1.20
Se	0.010	0.182	L	L	0.09	0.06
Zn	0.012	0.043	L	L	0.03	0.46
Cl	15.17	344.	L	L	0.07	0.10
CN	--	0.032	-	L	--	0.32
SO ₄	791.1	3091.	L	L	0.18	0.08
SO ₃	--	1395.	-	L	--	0.50

* H or L = Leachate from treated sludge column has higher or lower concentration than that of untreated control. T/U = concentration in leachate from treated sludge column divided by that from untreated control.

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TABLE 22. PERCENT OF SELECTED CONSTITUENTS LEACHED FROM PRIORITY COLUMNS CONTAINING SLUDGE TREATED BY PROCESS A COMPARED WITH UNTREATED CONTROL COLUMNS

Constituent	Lime Process Eastern Coal Sludge 100		Limestone Process Eastern Coal Sludge 400		Double-Alkali Eastern Coal Sludge 500		Lime Process Western Coal Sludge 600		Double Alkali Western Coal Sludge 1000		Median ^a T/U	Σ Low	Median Ht or Lo
	Σ	Ht or Lo	Σ	Ht or Lo	Σ	Ht or Lo	Σ	Ht or Lo	Σ	Ht or Lo			
As	0.770	H	1.537	H	7.597	H	0.348	H	-	-	7.4	0	H
Be	0.079	L	0.073	L	0.225	H	0.047	L	0.195	L	0.29	80	L
Ca	1.447	H	1.148	H	0.164	H	2.328	H	0.407	H	1.4	0	H
Cd	0.228	H	0.920	H	0.737	H	0.201	H	1.067	H	30	0	H
Cr	0.057	L	0.139	H	0.154	L	0.133	L	0.370	H	0.65	60	L
Cu	1.189	H	0.117	L	1.113	H	0.167	H	5.922	H	5.8	20	H
Mg	1.230	H	0.657	H	0.123	H	0.348	L	0.328	H	4.4	20	H
Mn	0.006	L	0.768	H	0.049	H	0.405	L	2.870	H	1.2	40	H
NI	0.067	L	0.078	L	0.426	L	0.226	L	0.811	L	0.27	100	L
Pb	0.665	H	0.527	H	1.642	H	1.038	H	2.538	H	2.9	0	H
Zn	0.025	L	0.054	L	0.021	H	0.048	L	0.958	H	0.96	60	L
Cl	0.140	L	0.165	L	0.830	H	1.549	L	0.320	L	0.26	80	L
SO ₄	3.258	L	2.089	L	3.495	L	4.466	L	2.151	L	0.63	100	L
Σ Low	54%		46%		23%		62%		33%			46%	

^a T/U = % leached from treated divided by % leached by untreated sludge column.
H or L = percent leached from treated sludge column higher or lower than that of untreated control column.
NOTE: Data from which these figures are derived are given in Appendix B.

TABLE 23. CONCENTRATION OF SELECTED CONSTITUENTS IN LEACHATE FROM PRIORITY COLUMNS CONTAINING SLUDGES TREATED BY PROCESS B

Constituent	Lime Process ^a		Limestone Process ^b		Double Alkali		Lime Process		Double Alkali	
	Eastern Coal Sludge 100	Highest	Eastern Coal Sludge 400	Highest	Eastern Coal Sludge 500	Highest	Western Coal Sludge 600	Highest	Western Coal Sludge 1000	Highest
As	0.032	0.14	0.004	0.005	0.001	0.012	0.018	0.078	0.003	0.015
Be	*	*	0.001	0.004	*	*	*	0.001	*	0.001
Ca	39.16	339.0	39.53	1239.	264.9	798.9	10.34	23.0	94.90	600.0
Cd	*	0.006	0.001	0.117	*	0.001	*	0.002	0.002	0.009
Cr	0.003	0.075	0.004	0.090	0.009	0.064	0.005	0.045	0.044	0.149
Cu	0.003	0.014	0.005	0.067	0.002	0.010	0.009	0.028	0.013	0.080
Mg	0.018	0.100	0.053	1.000	0.026	0.200	0.024	0.200	0.177	3.100
Mn	0.004	0.029	0.018	3.392	0.001	0.010	0.004	0.031	0.015	0.240
NI	0.010	0.115	0.085	0.117	0.045	0.526	0.009	0.054	0.036	0.275
Pb	0.002	0.009	*	0.056	0.004	0.016	0.002	0.013	0.074	0.499
Se	*	0.005	*	0.123	*	0.006	0.003	0.056	*	0.014
Zn	0.007	0.080	0.046	0.017	0.004	0.050	0.014	0.100	0.008	0.070
Cl	206.8	781.0	1.264	102.	25.05	153.0	483.9	1562.	210.2	1320.
CB	*	0.020	0.001	0.010	*	0.020	*	0.010	*	0.100
SO ₄	292.9	700.0	470.8	5700.	3130.	18490.	565.7	1139.	3352.	20990.
SO ₃	475.0	1630.	11.44	260.	12.51	260.	485.	1450.	1450.	1450.
Average pH	10.61						10.71		11.81	

* Below one microgram/liter.

a. In mg/l. Overall is total mg leached/total volume leachate collected; highest is highest concentration found in any individual sample.

b. Sample disintegrated on day 15; data not complete.

untreated samples. All heavy metals had maximum concentration levels less than 30 percent that of the untreated sludge leachate levels (Table 24).

The comparison of percent leached with that of the untreated material or controls (Table 25) indicates that a large part of the apparent benefit of stabilization is lost if the total amount of material leached is calculated on the basis of the amount of dry sludge solids incorporated into the system. Overall, less than half of those constituents measured were more efficiently retained in the treated sludge when the fraction leached is considered.

Process E, which uses cement and fly ash additives to form a final product similar to concrete, produced fixed sludges which had leachates with lower average concentrations of potential contaminants except for copper, lead, and zinc (Tables 26 and 27). The maximum concentrations in leachate samples were also markedly lower except in the cases of lead, zinc, and cyanide (Table 27).

Calculation of the percent leached (Table 28) for process E did not greatly diminish the apparent gain from the fixation process. Here 67 percent of the constituents were leached at lower rates than in the controls (untreated sludges).

Process F, which was only used to treat two of the FGC sludges (lime process sludges 100 and 600) uses a cementitious additive derived from basic, glassy slag. Sludges fixed by process F produced leachates with lower average levels for all constituents except calcium and lead (Table 29). The only maximum level for any constituent that was greater than that found in raw sludge leachate is cyanide which was found at over 6 mg/L in at least one sample from both columns 100F and 600F. When the fraction or percentage loss from the solidified sludge is compared to losses of corresponding materials from untreated columns, less than one-third of the constituents studied were more effectively retained in the solidified materials (Table 30).

Process G uses cement kiln dust as an additive and pH adjustment with sulfuric or phosphoric acid to produce a solid mass. The results of the pH adjustment can be seen in the low pH of the leachate (averaging 7.4). This process resulted in a product whose leachate exceeded the untreated sludge leachate in the average concentration of five constituents: calcium, copper, magnesium, lead, and chloride (Tables 31 and 32). The leachate from these columns also had maximum concentration levels which exceeded those of untreated sludge columns for copper, magnesium, chloride, and cyanide. The very high levels of magnesium and chloride leached from these columns may reflect their addition in the cement kiln dust.

On a percentage basis, none of the constituents measured could be shown to be more effectively retained in the wastes solidified using process G. (Table 33). Process G was completely unsuccessful in lowering the proportion of material that was leached from the sludges. The magnesium and chloride added in the solidification process must account for the fact that over 100 percent of these constituents loaded into the column was lost from several test columns.

The range of values for the ratios generated in the three different

TABLE 24. AVERAGE AND HIGHEST INDIVIDUAL CONCENTRATION OF CONSTITUENTS IN LEACHATE FROM ALL PRIORITY SLUDGE COLUMNS TREATED BY PROCESS B, AS COMPARED TO UNTREATED CONTROL COLUMNS

Constituent	Average Overall	Highest Of All	Relative to Untreated Columns*		
			Average Overall	Highest	Highest Overall T/U
As	0.012	0.140	L	L	0.26
Be	--	0.004	L	L	--
Ca	85.76	1239.	L	H	0.26
Cd	--	0.117	L	L	--
Cr	0.013	0.149	L	L	0.20
Cu	0.006	0.080	L	L	0.22
Mg	0.060	3.100	L	L	0.01
Mn	0.008	3.392	L	L	0.02
NI	0.041	0.526	L	L	0.06
Pb	0.021	0.499	H	L	1.62
Se	--	0.123	-	L	--
Zn	0.016	0.100	L	L	0.94
Cl	185.0	1562.	L	L	0.94
CN	--	0.100	-	L	--
SO ₄	1562.	20990.	L	L	0.35
SO ₃	--	1630.	-	L	--

* H or L = Leachate from treated sludge column has higher or lower concentration than that of untreated control. T/U = concentration in leachate from treated sludge column divided by that from untreated control.

TABLE 25. PERCENT OF SELECTED CONSTITUENTS LEACHED FROM PRIORITY COLUMNS CONTAINING SLUDGE TREATED BY PROCESS B, COMPARED TO UNTREATED CONTROL COLUMNS

Constituent	Lime Process Eastern Coal Sludge 100		Limestone Process Eastern Coal Sludge 400b		Double Alkali Eastern Coal Sludge 500		Lime Process Western Coal Sludge 600		Double Alkali Western Coal Sludge 1000		Median T/U	Median H1 or Lo
	%	H1 or Lo	%	H1 or Lo	%	H1 or Lo	%	H1 or Lo	%	H1 or Lo		
As	1.446	H	0.036	L	0.036	L	2.036	H	-	-	3.1	H
Be	0.003	L	0.013	L	0.013	L	0.010	L	0.010	L	0.014	L
Ca	0.216	L	2.462	H	2.462	H	0.183	L	0.517	H	1.1	H
Cd	0.007	H	0.009	L	0.009	L	0.013	L	0.057	L	0.29	L
Cr	0.042	L	0.117	L	0.117	L	0.097	L	0.746	H	0.42	L
Cu	0.101	H	0.74	L	0.74	L	0.364	H	1.281	H	2.7	H
Mg	0.006	L	0.009	H	0.009	H	0.009	L	0.141	L	0.33	L
Mn	0.048	H	0.016	L	0.016	L	0.051	L	0.381	H	0.76	L
Ni	0.163	L	1.169	H	1.169	H	0.291	L	1.108	H	0.87	L
Pb	0.195	H	0.216	L	0.216	L	0.100	L	2.652	H	1.5	H
Zn	0.097	H	0.032	H	0.032	H	0.106	L	0.214	H	2.65	H
Cl	5.995	H	0.611	H	0.611	H	15.90	H	16.7	-	2.2	H
SO ₄	2.318	L	19.47	H	19.47	H	10.71	H	9.509	H	1.65	H
Percent Low	46%		54%		54%		69%		27%		49%	46%

a. T/U = % leached from treated divided by % leached by untreated sludge column. H1 or Lo = % leached from treated sludge columns higher or lower than that of untreated control column.

b. Sample disintegrated on Day 154; data not complete.

Note: Data from which these figures are derived are given in Appendix B.

TABLE 26. CONCENTRATION OF SELECTED CONSTITUENTS IN LEACHATE FROM PRIORITY COLUMNS CONTAINING SLUDGES TREATED BY PROCESS E

Constituent	Lime Process ^a Eastern Coal Sludge 100		Limestone Process Eastern Coal Sludge 400		Double Alkali Eastern Coal Sludge 500		Lime Process Western Coal Sludge 600		Double Alkali Western Coal Sludge 1000	
	Overall	Highest	Overall	Highest	Overall	Highest	Overall	Highest	Overall	Highest
As	0.001	0.011	0.003	0.012	0.001	0.006	0.003	0.012	0.001	0.007
Be	0.001	0.017	*	*	*	0.001	0.004	0.023	*	0.001
Ca	225.6	505.5	403.7	917.2	246.9	380.0	62.50	217.1	184.4	447.2
Cd	*	*	*	0.001	*	0.001	*	*	*	*
Cr	0.023	0.054	0.024	0.181	0.064	0.395	0.012	0.032	0.084	0.599
Cu	0.017	0.106	0.008	0.022	0.166	0.014	0.003	0.012	0.006	0.016
Mg	0.089	0.100	0.067	0.300	0.532	1.800	0.045	0.100	0.040	0.100
Mn	0.005	0.020	0.116	0.888	0.001	0.005	0.003	0.030	0.001	0.002
NI	0.005	0.022	0.025	0.054	0.034	0.385	0.034	0.178	0.006	0.026
Pb	0.002	0.008	0.002	0.006	0.216	1.799	0.230	0.900	0.003	0.020
Se	--	0.010	0.001	0.019	0.002	0.027	0.001	0.010	HD	HD
Zn	0.003	0.008	0.004	0.022	0.072	1.000	0.343	5.200	0.009	0.022
Cl	28.50	125.0	8.956	83.00	93.76	765.0	2.845	26.00	3.062	21.00
CH	*	0.070	0.039	0.130	*	0.010	*	0.090	HD	HD
NO ₃	158.	600.	11.14	111.	40.20	340.	HD	HD	16.24	142.0
NO ₂	99.12	382.8	26.57	186.80	58.60	250.0	HD	HD	47.03	238.8
SO ₄	17.98	74.00	534.6	1839.	1370.	4250.	155.5	842.	780.9	3509.
SO ₃	18.98	70.00	22.27	55.00	74.38	450.	6.001	16.	40.41	138.0
Average pH	10.80		11.24		12.09		10.40		11.59	

* Below one microgram/liter.

a. In mg/l. Overall is total mg leached/total volume leachate collected; highest is highest concentration found in any individual sample.

TABLE 27. AVERAGE AND HIGHEST INDIVIDUAL CONCENTRATION OF CONSTITUENTS IN LEACHATES FROM ALL PRIORITY SLUDGE COLUMNS TREATED BY PROCESS E AS COMPARED TO UNTREATED CONTROL COLUMNS

Constituent	Average Overall	Highest Of All	Relative to Untreated Columns*		
			Average Overall	Highest	Highest T/U
As	0.001	0.012	L	L	0.05
Be	0.002	0.023	L	L	0.16
Ca	224.6	977.2	L	L	0.67
Cd	--	--	L	L	--
Cr	0.041	0.599	L	L	0.63
Cu	0.040	0.106	H	L	1.48
Mg	0.154	1.800	L	L	0.03
Mn	0.025	0.888	L	L	0.06
Ni	0.016	0.385	L	L	0.02
Pb	0.091	1.299	H	H	7.00
Se	0.001	0.027	L	L	0.001
Zn	0.086	5.200	H	H	5.06
Cl	27.42	765.0	L	L	0.14
CN	--	0.130	-	H	1.30
NO ₃	56.42	600.0	-	-	--
NO ₂	57.83	382.8	-	-	--
SO ₄	571.8	4250.	L	L	0.13
SO ₃	32.41	450.	-	L	--

* H or L = Leachate from treated sludge column has higher or lower concentration than that of untreated control. T/U = concentration in leachate from treated sludge column divided by that from untreated control.

TABLE 28. PERCENT OF SELECTED CONSTITUENTS LEACHED FROM PRIORITY LEACHING COLUMNS CONTAINING SLUDGE TREATED BY PROCESS E AS COMPARED TO UNTREATED CONTROL COLUMNS

Constituent	Lime Process Eastern Coal Sludge 100		Limestone Process Eastern Coal Sludge 400		Double-Alkali Eastern Coal Sludge 500		Lime Process Western Coal Sludge 600		Double Alkali Western Coal Sludge 1000		Medial ^a T/U		Median HI or Lo	
	$\bar{x}$	HI or Lo	$\bar{x}$	HI or Lo	$\bar{x}$	HI or Lo	$\bar{x}$	HI or Lo	$\bar{x}$	HI or Lo	$\bar{x}$	Low	$\bar{x}$	Low
As	0.040	L	0.260	H	0.028	L	0.109	H	-	-	0.89	50	L	L
Be	0.113	L	0.007	L	0.014	-	0.278	L	0.022	L	0.30	100	L	L
Ca	0.774	L	3.511	H	0.780	H	0.380	L	1.227	H	1.8	40	H	H
Cd	0.003	-	0.007	L	0.004	L	0.003	L	0.007	L	0.37	100	L	L
Cr	0.141	H	0.258	H	0.466	H	0.070	L	4.756	H	1.6	20	H	H
Cu	0.346	H	0.160	H	2.793	H	0.041	L	0.712	H	1.6	20	H	H
Mg	0.008	L	0.001	L	0.104	H	0.001	L	0.038	L	0.10	80	L	L
Mn	0.043	H	1.043	H	0.008	L	0.013	L	0.018	L	0.25	60	L	L
NI	0.051	L	0.365	L	0.349	L	0.367	L	0.236	L	0.22	100	L	L
Pb	0.158	H	0.387	H	7.046	H	4.409	H	0.118	L	4.1	20	H	H
Zn	0.021	L	0.040	L	0.302	H	1.942	H	0.292	H	6.9	40	H	H
Cl	0.519	L	0.571	H	1.294	H	0.070	L	0.297	L	0.38	60	L	L
SO ₄	0.089	L	1.755	L	4.819	L	1.013	L	2.706	L	0.45	100	L	L
$\bar{x}$ Low		67%		46%		42%		77%		67%				67%

a. T/U = $\bar{x}$ leached from treated divided by $\bar{x}$ leached by untreated sludge column.
H or L = percent leached from treated sludge columns higher or lower than that of untreated control column.

Note: Data from which these figures are derived are given in Appendix B.

TABLE 29. CONCENTRATIONS OF SELECTED CONSTITUENTS IN LEACHATE FROM PRIORITY COLUMNS CONTAINING SLUDGES TREATED BY PROCESS F AND COMPARISON WITH UNTREATED CONTROL COLUMNS

Constituent	Line Process ^a Eastern Coal Sludge 100		Line Process Western Coal Sludge 600		Average Overall	Highest Of All	Relative to ^b Untreated Sludge			
	Overall	Highest	Overall	Highest			Overall	Highest	Avg Overall	Highest T/U
As	0.039	0.017	0.010	0.010	0.025	0.010	L	L	0.54	0.16
Be	0.001	0.010	0.001	0.008	0.001	0.010	L	L	0.14	0.07
Ca	668.7	718.9	401.8	568.9	535.2	718.9	H	L	1.59	0.59
Cd	0.002	0.017	0.001	0.002	0.002	0.17	L	L	0.40	0.02
Cr	0.006	0.049	0.044	0.262	0.025	0.262	L	L	0.38	0.04
Cu	0.003	0.019	0.047	0.256	0.025	0.256	L	L	0.92	0.06
Mg	0.635	1.100	0.309	0.800	0.461	1.100	L	L	0.08	0.003
Mn	0.002	0.004	0.005	0.025	0.003	0.025	L	L	0.01	0.002
NI	0.213	0.694	0.158	0.597	0.166	0.694	L	L	0.22	0.30
Pb	0.001	0.005	0.071	0.600	0.042	0.600	H	L	3.23	0.60
Se	ND	ND	ND	ND	ND	ND	-	-	-	-
Zn	0.012	0.044	0.008	0.050	0.010	0.050	L	L	0.59	0.05
Cl	102.9	581.	101.0	561.0	102.0	581.0	L	L	0.52	0.16
CH	--	6.030	--	6.23	--	6.23	-	H	-	62.3
SO ₄	1215.	1389	737.4	1289.	976.0	1389.	L	L	0.21	0.03
SO ₃	--	550.	--	195.0	--	550.	L	L	-	-
Average pH	8.73		8.71		8.72					

a. In mg/l, ND = no data. Overall is total mg leached/total liters leachate; highest is highest concentration found in any individual sample.
b. H or L = Leachate from treated sludge column has higher or lower concentration than that of untreated control. T/U = concentration in leachate from treated sludge column divided by that from untreated control.

TABLE 30. PERCENT OF SELECTED CONSTITUENTS LEACHED FROM PRIORITY COLUMNS CONTAINING SLUDGE TREATED BY PROCESS F COMPARED WITH UNTREATED SLUDGE COLUMNS

Constituent	Lime Process Eastern Coal Sludge 100		Lime Process Western Coal Sludge 600		%	Avg ^a		Avg ^b	
	%	Hi or Lo	%	Hi or Lo		Low	T/U	Hi	Lo
As	1.508	H	0.477	H	0	5.8		H	
Be	0.070	L	0.144	L	100	0.23		L	
Ca	3.098	H	3.052	H	0	2.3		H	
Cu	0.038	H	0.015	L	50	6.6		H	
Cr	0.051	L	0.358	H	50	0.83		L	
Cu	0.126	H	0.796	H	0	4.8		H	
Mg	0.247	L	0.055	L	100	0.46		L	
Mn	0.024	L	0.025	L	100	0.32		L	
NI	2.968	H	2.115	H	0	6.6		H	
Pb	0.065	H	1.702	H	0	2.5		H	
Zn	0.112	H	0.059	L	50	2.3		H	
Cl	2.533	H	3.098	L	50	1.15		H	
SO ₄	8.157	H	59.99	H	0	5.5		H	
% Low		31%		46%					31%

a. T/U = Percent leached from treated sludge column divided by percent leached from untreated sludge column.

b. H or L = Percent leached from treated sludge column had higher or lower concentration than that of untreated control column.

TABLE 31. CONCENTRATIONS OF SELECTED CONSTITUENTS IN LEACHATE FROM PRIORITY COLUMNS CONTAINING SLUDGES TREATED BY PROCESS G

Constituent	Lime Process ^a Eastern Coal Sludge 100		Limestone Process Eastern Coal Sludge 400		Double Alkali Eastern Coal Sludge 500		Lime Process Western Coal Sludge 600		Double Alkali Western Coal Sludge 1000	
	Overall	Highest	Overall	Highest	Overall	Highest	Overall	Highest	Overall	Highest
As	0.016	0.031	0.015	0.044	0.064	0.140	0.010	0.018	0.022	0.045
Be	0.005	0.080	0.005	0.070	0.003	0.062	0.006	0.120	0.007	0.102
Ca	529.8	1090.	475.0	900.0	505.7	1010.	509.0	936.0	522.9	1070.
Cd	0.006	0.020	0.006	0.020	0.004	0.020	0.006	0.020	0.005	0.020
Cr	0.018	0.093	0.014	0.123	0.009	0.080	0.015	0.083	0.011	0.054
Cu	0.016	0.050	0.007	0.027	0.017	0.033	0.005	0.020	0.179	3.699
Mg	70.46	227.0	205.1	569.5	127.0	600.0	149.3	564.0	103.2	465.0
Mn	0.030	0.085	0.079	0.150	0.023	0.100	0.102	0.230	0.034	0.110
Mo	0.138	0.420	0.091	0.388	0.096	0.434	0.144	0.532	0.174	0.499
Pb	0.140	1.800	0.094	1.200	0.324	1.400	0.045	1.000	0.001	1.000
Se	0.015	0.172	0.016	0.233	0.011	0.220	0.005	0.098	0.013	0.224
Zn	0.015	0.030	0.009	0.031	0.007	0.027	0.017	0.075	0.005	0.025
Cl	691.1	7498.	664.0	5998.	863.7	10100.	610.3	6998.	542.1	6598.
CM	0.010	0.010	0.006	0.020	--	0.010	0.010	0.010	0.010	0.010
SO ₄	669.3	8989.	3706.	8329.	4459.	9239.	2524.	5489.	4495.	16739.
SO ₃	6.000	6.000	6.413	7.000	60.000	60.000	6.000	6.000	85.000	85.000
Average pH	7.12	7.12	7.25	7.25	7.66	7.66	7.89	7.89	7.12	7.12

a. In mg/l, overall is total mg leached/total volume leachate; highest is highest concentration found in any individual sample.

TABLE 32. AVERAGE AND HIGHEST INDIVIDUAL CONCENTRATION OF CONSTITUENTS IN LEACHATES FROM ALL PRIORITY SLUDGE COLUMNS TREATED BY PROCESS G, AS COMPARED TO UNTREATED CONTROL COLUMNS

Constituent	Average Overall	Highest Of All	Relative to Untreated Columns*		
			Average Overall	Highest	Highest T/U
As	0.025	0.140	L	L	0.53
Be	0.005	0.120	L	L	0.71
Ca	508.3	1090.	H	L	1.52
Cd	0.005	0.020	L	L	1.00
Cr	0.013	0.123	L	L	0.20
Cu	0.045	3.699	H	H	1.67
Mg	131.0	600.0	H	H	22.0
Mn	0.054	0.230	L	L	0.13
Mo	0.129	0.532	L	L	0.17
Pb	0.178	0.180	H	L	13.69
Se	0.011	0.233	L	L	0.10
Zn	0.011	0.075	L	L	0.65
Cl	674.5	10100.	H	H	3.44
CM	—	0.020	—	H	—
SO ₄	3230.	16739.	L	L	0.73
SO ₃	—	85.00	—	L	—

* H or L = Leachate from treated sludge column has higher or lower concentration than that of untreated control. T/U = concentration in leachate from treated sludge column divided by that from untreated control.

TABLE 33. PERCENT OF SELECTED CONSTITUENTS LEACHED FROM PRIORITY LEACHING COLUMNS CONTAINING SLUDGE TREATED BY PROCESS G AS COMPARED TO UNTREATED SLUDGE COLUMNS

Constituent	Lime Process		Limestone Process		Double-Alkali		Lime Process		Double Alkali		Median ^a Y/U	% Low	H or L	Median ^a H/L or L
	Eastern Coal Sludge 100	% H/L or L	Eastern Coal Sludge 600	% H/L or L	Eastern Coal Sludge 500	% H/L or L	Western Coal Sludge 600	% H/L or L	Western Coal Sludge 1000	% H/L or L				
As	0.460	L	6.719	H	12.28	H	2.628	H	---	---	25	25	H	H
Be	0.216	-	3.636	H	3.792	H	2.967	H	1.116	H	5.9	0	H	H
Ca	6.817	H	2.932	H	15.92	H	20.46	H	16.92	H	7.3	0	H	H
Cd	0.337	H	0.687	H	0.540	H	0.383	H	0.686	H	22.5	0	H	H
Cr	0.609	H	0.569	H	0.656	H	0.630	H	1.012	H	6.6	0	H	H
Cu	1.213	H	0.561	H	2.871	H	0.652	H	90.15	H	15.	0	H	H
Mg	76.11	H	210.5	H	256.3	H	140.9	H	629.4	H	1690.	0	H	H
Mn	0.740	H	6.538	H	1.432	H	2.716	L	6.631	H	35.	25	H	H
Mo	5.343	H	6.805	H	10.07	H	10.28	H	28.32	H	15.	0	H	H
Pb	41.12	H	58.04	H	108.0	H	5.713	H	25.34	H	48.	0	H	H
Zn	0.410	H	0.357	H	0.323	H	0.628	H	69.97	H	16.	0	H	H
Cl	47.33	H	86.38	H	121.9	H	98.94	H	225.5	H	34.	0	H	H
SO ₄	65.14	H	13.164	H	164.0	H	108.6	H	68.49	H	15.	0	H	H
% Low		H		H		H		H		H				OX

^a Y/U = % leached from treated sludge column divided by % leached by untreated sludge column. H or L = percent leached from treated sludge column has higher or lower value than that of untreated control column.

NOTE: Data from which these figures are derived are given in Appendix B.

methods of handling the data is shown in graphic form in Figures 19, 20, and 21. The value of the T/U ratio for each processor is given by the position of their processor identification letter for each constituent that was tested. A T/U ratio value of less than one indicates that the leachate from the stabilized sludge had a lower ratio for the constituent than the leachate from the similar unstabilized sludge column. These figures show the efficiency of each process's containment of each sludge constituent and compares them directly with the results from the other processes.

The range of values for T/U ratios when average concentrations of the selected constituents are considered is shown in Figure 19. The grouping of the values in Figure 19 indicates that the ability of solidification systems to contain any particular constituent, varies greatly with the nature of the constituent. The greatest effect of solidification could be observed with beryllium, magnesium, manganese, nickel, and selenium. The concentrations of these metals in leachate from treated sludges varied between one-hundredth and one-tenth of their concentration in the leachate from the untreated sludges. Arsenic, chromium, chloride and sulfate loss appears to be only slightly reduced by stabilization (T/U values are between one-tenth and one). Calcium, copper, and zinc on the whole are not strongly effected by stabilization at all. The concentration of lead is consistently higher in leachate from stabilized sludges.

A similar plot showing ratio of the highest concentration of a constituent in leachate from a treated sludge, to the highest concentration of the same constituent in leachate from an untreated sludge, is given in Figure 20. The pattern is similar to the previous figure except that the ratios are displaced to the left. This shows that stabilization of the sludges more strongly effects the maximum concentration values more than the average concentrations. Those constituents showing the greatest reduction in maximum concentration were magnesium, manganese, and selenium. Beryllium, cadmium, chromium, nickel, and sulfate also showed appreciable reductions in maximum concentrations.

Figure 21 shows a plot of the ratio of the median percent of each sludge constituent leached from the treated sludge columns to the percent leached from the untreated sludge columns. The best retention of potentially polluting constituents (measured on this percent basis) occurs with beryllium, magnesium, nickel, and manganese. For many constituents, stabilization does not appreciably increase the percent retained. In at least some cases, the stabilized materials actually increase the percent of constituents lost above levels observed in untreated materials. This was observed to occur with calcium, copper, lead and zinc in all of the treated materials.

SUMMARY OF CHEMICAL LEACHING DATA

In general, the average concentrations of many of the constituents in the leachates collected over the duration of this study were reduced by solidification/stabilization. This suggests that solidified FGD wastes will show a reduced impact on the quality of surrounding groundwater when compared to untreated FGD wastes.

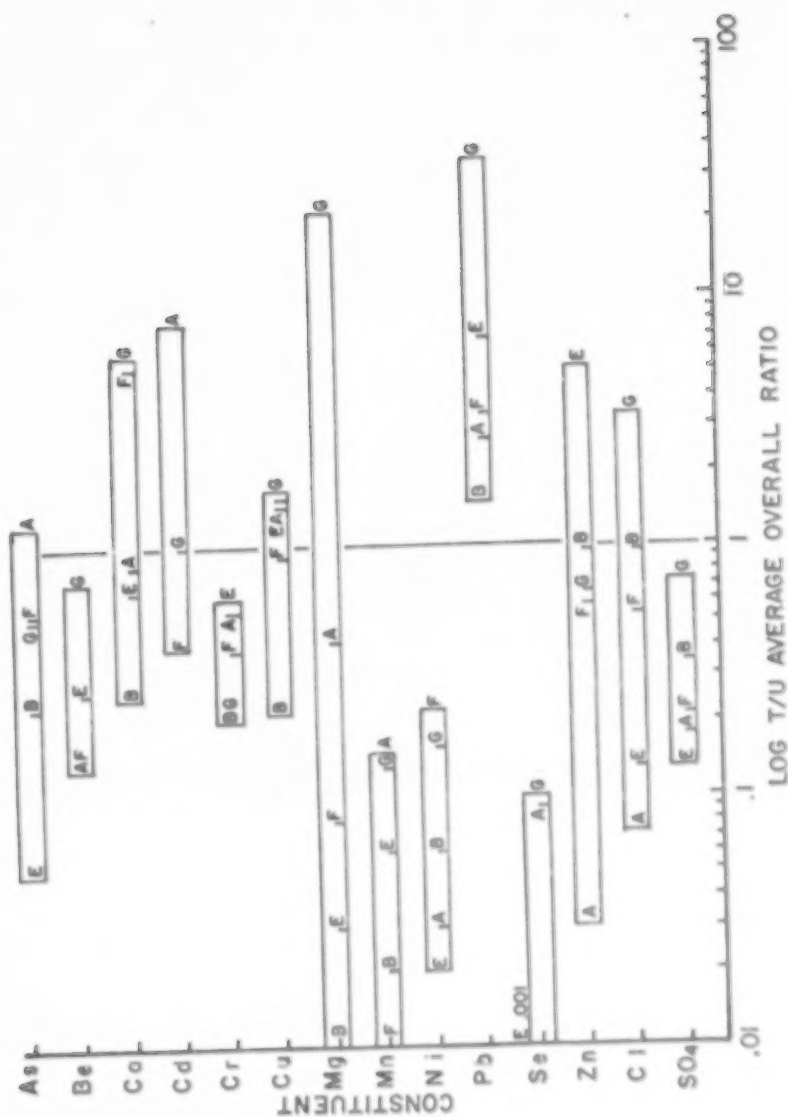


Figure 19. Plot of the ratio of the average concentration of each constituent in the leachate from treated columns to the average concentration of the corresponding constituent in the leachate from untreated columns. The letters refer to the processes used in solidification/stabilization.

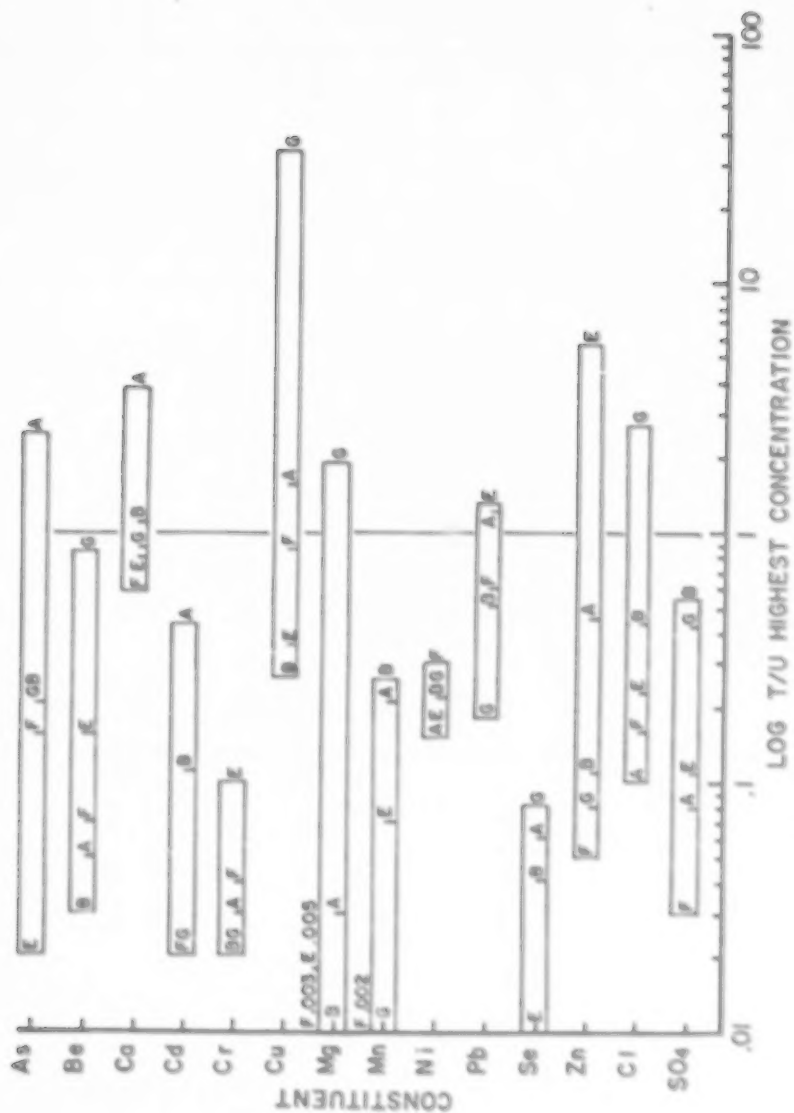


Figure 20. Plot of the ratio of the highest concentration of each constituent in the leachate from treated columns to the highest concentration of the corresponding constituent in the leachate from untreated columns. The letters refer to the processes used in solidification/stabilization.

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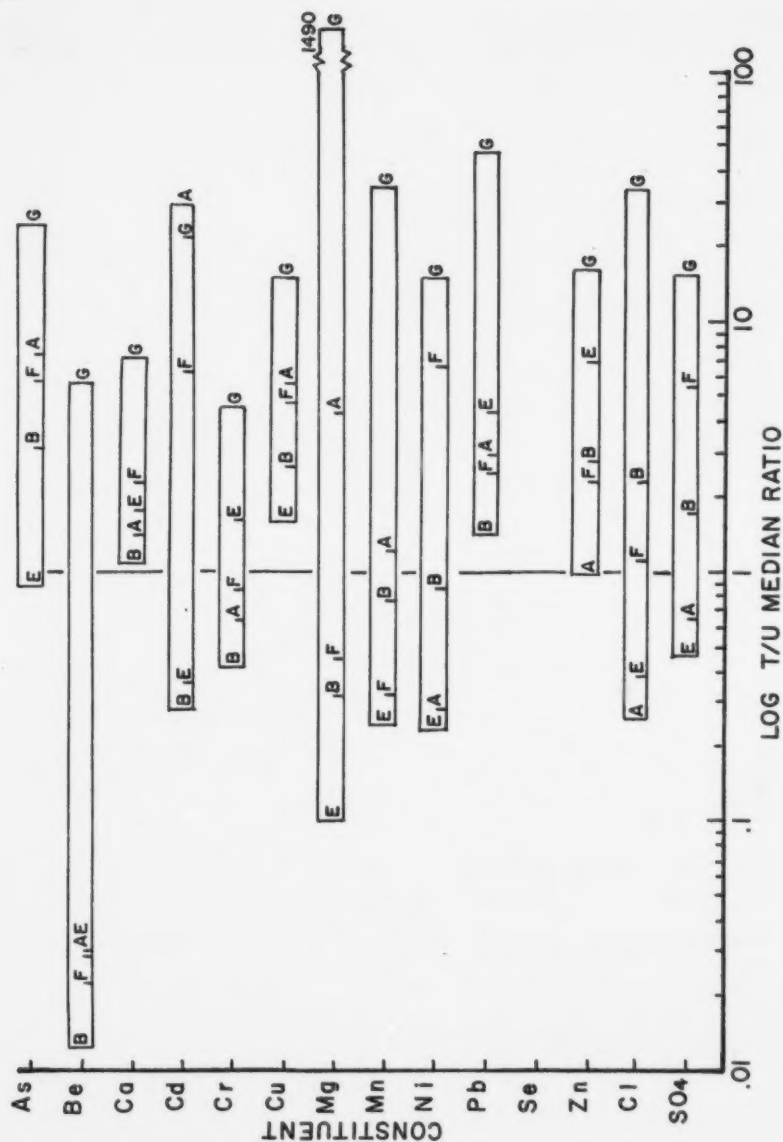


Figure 21. Plot of the ratio of the median percent leached of each constituent in the leachate from treated columns to the median percent of the corresponding constituent in the leachate from the untreated columns. The letters refer to the processes used in solidification/stabilization.

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The greatest effect of the fixation process (as seen in this study) is the reduction of the maximum concentrations of released materials in the leachate. In an operating landfill where fresh wastes are added daily, this ability to prevent maximum possible concentrations observed in leachate from untreated material from occurring may be the major benefit solidification will produce.

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In any treatment process, it is important to consider the amount of material lost in relation to the amount of dry sludge solids actually included in the treated product. When the proportion of dry sludge solids was taken into consideration in this study (as percent loss, Figure 20), many of the apparent benefits of solidification were diminished. Two possible problems in the treatment processes could be seen in this study. In some cases, leachable material appears to have been added in the reagent that produces the solidifying or stabilizing reaction such that greater amounts of certain constituents are released from the treated sludge than were released in the original untreated wastes. In other cases, the treatment process appears to alter the chemical conditions in the sludge so as to increase the solubility of certain constituents above the level found for the original untreated wastes. Consequently more material was lost from the treated waste than from the equivalent weight of untreated wastes.

The overall effectiveness of any treatment process can probably be best evaluated by examining all the plots and observing which processes produce the lowest (smallest) T/U ratios in each plot for the most troublesome sludge constituents. Unfortunately, no single process can be said to be optimum, based on all three criteria (low average leachate concentration, lowest maximum concentration observed, and lowest percent leached) as applied to all fourteen parameters considered.

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SECTION 7

DISCUSSION

GENERAL COMMENTS

Solidification and stabilization of industrial wastes using admixing processes is generally thought to be achieved by isolating the waste materials and/or by creating chemical conditions that reduce the solubility or chemical reactivity of the compounds in the waste. Isolation of the waste can be brought about by encapsulating the waste within some inert material or by reducing the effective surface area of the waste by forming an impermeable monolith.

If the preceding assumptions are valid, it should be possible to judge the effectiveness of a solidification process by examining critical physical properties, such as permeability, density, void space, and durability. Permeability would be an indication of the rate of movement of water and dissolved material into and out of the treated solid. An increase in density would indicate a decrease in void space, and loss of permeability. Reduced void space would be a second indication of lowered permeability. Durability would aid in estimating the long-term effectiveness of the solidification process in isolating the wastes.

Chemical attributes which should be of predictive value in estimating effectiveness of containment would include the pH of the end product and the solubility and reactivity of new compounds produced in the stabilization/solidification process. Ultimately, the true test of chemical binding or containment would be a well-designed leach test.

SOLIDIFICATION PERFORMANCE

In this evaluation program, care was taken to assess both physical and chemical properties of the processed and unprocessed material. Based on the results of the 2-year duration leaching test, it appears that the physical properties thought important in assessing the effectiveness of solidification techniques are of only moderate predictive value. For example, process B that has a low density, highly permeable, soil-like material could be judged from the leaching test to be moderately effective. Process G, on the other hand, had a lower void ratio than process B, similar permeability and higher durability, but showed relatively poor containment properties when leach tested. Process E did show the predicted relationship between physical properties and leaching. Samples from the process E had very low permeability, a low void

ratio, and excellent durability in both wet-dry and freeze-thaw tests. Samples prepared using this process were judged to perform well in the leach testing.

Slurry pH appeared to be a factor that was correlated with containment effectiveness. Process G, which was the least effective in terms of containment in the leach test, also exhibited the lowest pH. Processes B and E, which showed a relatively high degree of waste containment, had high slurry pH's (10 to 12). In general, any process that requires acidification, either for pH adjustment or for catalyzing a polymerization reaction, seems to have greater leaching problems than a processing system that does not use acid or acid-producing catalysts. An acid-treatment of wastes appears to bring more material into solution and to make the waste more prone to potential pollutant loss.

LEACH TESTING PROCEDURES

The specific conditions under which leach testing is conducted have a great effect on the performance of any stabilization process. The test procedure used here requires the specimens to be constantly immersed in water saturated with carbon dioxide. These conditions do not duplicate those found in a typical waste disposal site. These conditions cause reactions such as hydration of the calcium aluminum silicates in the cement additives and support biological activity that may accelerate the release of potential contaminants. The carbon dioxide-saturated leaching solution is an aggressive leaching medium that has a low pH (4.5) and forms soluble bicarbonate complexes with many alkali, alkali earth and transition metals.

While results of small-scale leach testing can be used with confidence in comparing one sample to another within a small-scale study, extrapolation to field conditions should not be attempted. When transport of possible contaminants is considered in a waste solid, the relationship between the surface area exposed and the volume of waste is critical. Most landfilled wastes would have far lower surface area-to-volume ratios than the small samples used in any bench-scale testing.

This limited study forms a basis for future research in comparing the effectiveness of different solidification/stabilization processes applied to FGC sludges. A complete evaluation of the effectiveness of solidification/stabilization processes will require projects on a scale that more faithfully reproduces conditions in the landfill environment.

REFERENCES

1. Rossoff, Jerome. Introduction to FGD By-Product Disposal/Utilization Sessions. In Proceedings: Symposium on Flue Gas Desulfurization. Hollywood, Florida, November 1977, EPA-600/7-78-058b, U. S. Environmental Protection Agency, Cincinnati, Ohio, 1978. pp. 437-438.
2. Holighaus, Rolf. Desulfurization Technology in The Federal Republic of Germany. In Proceedings: Symposium on Flue Gas Desulfurization, Hollywood, Florida, November 1977, EPA-600/7-78-058a, U. S. Environmental Protection Agency, Cincinnati, Ohio, 1978. pp. 80-95.
3. Baker, Michael Jr., Inc. State-of-the-Art FGD Sludge Fixation. Final Report FP-671, Vol. 3. Electric Power Research Inst., Palo Alto, California, 1978. 276 pp.
4. Lunt, R. R. and others. Evaluation of the Disposal of Flue Gas Desulfurization Wastes in Mines and the Ocean: Initial Assessment. EPA-600/7-77-051, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1977. 318 pp.
5. Geswein, Allen J. FGD Sludge Disposal: New Regulatory Initiatives. In Proceedings: Symposium on Flue Gas Desulfurization. Hollywood, Florida, November 1977. EPA-600/7-78-058b, U. S. Environmental Protection Agency, Cincinnati, Ohio, 1978. pp. 439-452.
6. Malone, P. G. and L. W. Jones. The Effects of Ash and Flue Gas Cleaning Waste on Groundwater Quality and Soil Characteristics. U. S. Environmental Protection Agency, Cincinnati, Ohio, In Press.
7. Weaver, D. E., C. J. Schmidt and J. P. Woodyard. Data Base for Standards/Regulations Development for Land Disposal of Flue Gas Cleaning Sludges. EPA-600/7-77-118, U. S. Environmental Protection Agency, Cincinnati, Ohio, December 1977. 299 pp.
8. Selmeczi, J. G. and R. G. Knight. Properties of Power Plant Waste Sludges. Presented at the Third International Ash Utilization Symposium, Pittsburgh, Pennsylvania, March 13-14, 1973. 28 pp.
9. Mahloch, J. L., D. E. Averett, M. J. Bartos, Jr. Pollutant Potential of Raw and Chemically Fixed Hazardous Industrial Wastes and Flue Gas Desulfurization Sludges-Interim Report. EPA-600/2-76-182, U. S. Environmental Protection Agency, Cincinnati, Ohio, 1976. 117 pp.

10. Landreth, R. E. and J. L. Mahloch. Chemical Fixation of Wastes. In Industrial Water Engineering, July/August 1977. pp. 16-19.
11. U. S. Environmental Protection Agency. Manual of Methods of Chemical Analysis of Water and Wastes. EPA 652/6-74-003a. U. S. Environmental Protection Agency, Cincinnati, Ohio, 1974. 298 pp.
12. Bartos, M. J., Jr. and M. R. Palermo. Physical and Engineering Properties of Hazardous Industrial Wastes and Sludges. EPA-600/2-77-139. U. S. Environmental Protection Agency, August 1977. 89 pp.
13. U. S. Dept. of the Army. Laboratory Soils Testing. Engineering Manual EM 1110-2-1906, U. S. Dept. of the Army, Washington, DC, 1970. No Pagination.
14. American Society for Testing and Materials (ASTM). Annual Book of ASTM Standards, Part 11. Philadelphia, Pennsylvania, 1973. 717 pp.
15. Dutt, F. R. and K. K. Tanji. Predicting Concentrations of Solutes in Water Percolated Through a Column of Soil. J. Geophys. Res. 67:3437-3439. 1962.
16. Jurinak, J. J. and others. Cation Transport in Soils and Factors Affecting Soil Carbonate Solubility. EPA-R2-73-235, U. S. Environmental Protection Agency, Washington, DC, 1973. 87 pp.
17. Biggar, J. W. and D. R. Nielsen. Diffusion Effects in Miscible Displacement Occurring in Saturated and Unsaturated Porous Materials. J. Geophys. Res. 65:2887-2895, 1960.
18. Mangelsdorf, P. C. Difference Chromatography. Anal. Chem. 38: 1540-1544, 1966.
19. National Academy of Sciences-National Academy of Engineering. Water Quality Criteria-1972. EPA-R3-73-033, U. S. Environmental Protection Agency, 1973. 594 pp.

APPENDIX A

RESULTS FROM NON-PRIORITY LEACHING COLUMNS

Samples from each treated and untreated sludge type were placed in triplicate leaching columns which underwent similar loading and leaching conditions. Low-level analysis of metal concentrations were only made on the leachates from one of the triplicate set of columns--the priority columns from which the information in the body of this report was derived. This appendix gives the results of the leaching tests from the remaining two columns of each triplicate set--the non-priority columns. Detection limits used are presented in Table 5.

The only constituent concentrations consistently above the higher detection limits in the non-priority columns were calcium, magnesium, chloride and sulfate. All other constituents were only above detection limits in a few of the leachate samples from these columns. The data for all non-priority columns are given in a form comparable to that used for the priority columns in the body of this report in Tables A-1 through A-6. These tables give the average and highest concentrations found for the constituents of greatest interest, and the average volumes and pH values for all the leachate samples collected.

Analysis of these data indicate the same overall pattern of leachate composition, amounts, and pH as discovered for the priority columns. All columns had leaching rates averaging 2.5-3.5 liters per sampling interval, except for columns containing untreated sludge 500, the double alkali process, eastern coal sludge. These columns averaged only one liter per sampling period. The leachate from this sludge (500) also was over 1.5 pH units more basic than other leachates; averaging 11.5 and 12.3. The low leaching rate and high leachate pH may be responsible for the very high sulfate concentrations (averaging 2-3 percent) which must be the result of a very high loss of sodium sulfate from these sludge columns. The nature of this untreated sludge must also promote compaction and low permeability as the priority column had the same low flow rate. All four non-priority double alkali process sludge columns (500 and 1000) show this high sulfate, low calcium and high pH leachate. The western coal, double alkali columns consistently have the highest leachate production rates, while the eastern coal, double alkali sludge columns have the lowest.

Other characteristics of the leachate from the untreated non-priority columns which parallel those from the priority columns are the nearly saturated calcium sulfate from all but double alkali sludges and a higher chloride loss from both lime process sludges (100 and 600) and the western coal, double alkali sludge (1000). The pH of the leachates from the lime process, western

TABLE A-1. AVERAGE AND HIGHEST CONCENTRATIONS OF SELECTED CONSTITUENTS FROM NON-PRIORITY COLUMNS CONTAINING UNTREATED FGC SLUDGES.

Parameter	Lime Process, Eastern Coal Column 27 (1000 R)		Limestone Process, Eastern Coal Column 60 (400 R)		Double Alkali Process, Eastern Coal Column 65 (600 R)		Double Alkali Process, Eastern Coal Column 132 (500 R)	
	Avg.	Highest	Avg.	Highest	Avg.	Highest	Avg.	Highest
Viol (d)	2.36	4.5	2.40	4.5	3.24	4.5	3.21	4.5
pH	7.9	9.5	8.4	9.8	8.9	10.0	8.3	9.6
Ca	605	1070	670	1200	558	710	570	740
Co	--	--	--	--	--	9.05	--	--
Cr	--	--	--	--	--	--	--	--
Cu	--	--	--	0.3	0.2	0.2	0.3	0.5
Mg	2.15	8.40	3.90	35.0	0.80	2.40	1.10	2.40
Mn	--	0.6	0.6	1.1	--	--	--	--
Pb	--	--	--	--	--	--	--	--
Zn	--	--	--	--	--	--	--	--
Cl	545	1000	652	1000	16	31	60	196
SO ₄	1600	1800	1370	2140	1530	2440	1530	2140
Parameter	Lime Process, Western Coal Column 96 (600 R)		Lime Process, Western Coal Column 19 (400 R)		Double Alkali Process, Western Coal Column 43 (1000 R)		Double Alkali Process, Western Coal Column 45 (1000 R)	
	Avg.	Highest	Avg.	Highest	Avg.	Highest	Avg.	Highest
Viol (d)	3.01	4.5	2.85	4.5	3.57	4.5	3.45	4.5
pH	6.3	8.4	6.3	7.8	9.7	12.5	9.8	12.4
Ca	576	1000	578	816	129	629	54.4	151
Co	--	--	--	0.10	--	--	--	--
Cr	0.6	1.5	--	1.3	--	--	--	--
Cu	--	--	--	--	--	--	--	--
Mg	57.8	360	47.6	200	1.33	2.80	0.70	2.20
Mn	1.1	3.3	1.5	3.2	--	--	--	--
Pb	--	--	--	--	--	--	--	1.1
Zn	--	--	--	--	--	--	--	--
Cl	516	2170	838	3800	2470	7550	262	4700
SO ₄	1740	2390	2095	2720	6840	40990	6840	37800

NOTE: -- is below detection limits or no data; all in mg/l except volume and pH.

TABLE A-2. AVERAGE AND HIGHEST CONCENTRATIONS OF SELECTED CONSTITUENTS FROM NON-PRIORITY COLUMNS CONTAINING SLUDGES TREATED BY PROCESS A.

Parameter	Lime Process, Western Coal Column 31 (1000 A)		Limestone Process, Eastern Coal Column 106 (4000 A)		Double Alkali Process, Eastern Coal Column 107 (3000 A)		Double Alkali Process, Eastern Coal Column 12 (5000 A)	
	Avg.	Highest	Avg.	Highest	Avg.	Highest	Avg.	Highest
NaCl (g)	2.22	6.5	2.52	6.5	2.51	6.5	2.71	6.5
pH	8.5	9.3	8.9	9.5	8.2	9.2	9.7	12.3
Ca	649	1715	565	1240	562	727	66	249
Cl	0.04	0.10	0.10	0.30	0.10	0.15	0.15	0.16
Cr	..	..	..	..	..	..	..	..
Cu	0.5	1.0	0.6	0.7	..	..	..	..
Pb	2.39	16.3	3.79	6.90	3.40	6.20	0.27	0.10
Mn	..	..	0.6	1.2	1.2	1.2	..	..
Pb	..	..	..	..	..	1.2	..	..
Zn	..	..	..	..	..	..	..	..
Cl	69	207	15	35	8	10	99	312
SO ₄	1338	1740	1229	1659	1639	1775	1044	2550
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TABLE A-3. AVERAGE AND HIGHEST CONCENTRATIONS OF SELECTED CONSTITUENTS FROM NON-PRIORITY COLUMNS CONTAINING SLUDGES TREATED BY PROCESS B.

Parameter	Lime Process, Eastern Coal Column 129 (100 B)		Limestone Process, Eastern Coal Column 67 (400 B)		Double Alkali Process, Eastern Coal Column 91 (400 B)		Double Alkali Process, Eastern Coal Column 117 (500 B)		Eastern Coal Column 61 (500 B)	
	Avg.	Highest	Avg.	Highest	Avg.	Highest	Avg.	Highest	Avg.	Highest
Vol (L)	2.00	6.5	3.23	6.5	2.03	6.5	3.15	6.5	3.25	6.5
pH	10.0	13.0	10.3	12.5	11.5	12.5	11.3	12.6	11.7	13.0
Ca	16.6	29.0	54.0	290	764	1030	610	1210	532	8400
Cl	--	--	--	--	0.15	0.15	0.20	0.20	0.05	--
Cr	--	--	--	--	--	--	--	--	--	--
Cu	--	--	--	--	--	--	--	--	--	--
Hg	0.10	0.15	0.20	0.27	6.04	10.3	0.55	1.00	0.10	0.10
Mn	--	--	--	--	0.9	6.0	0.8	2.4	--	--
Pb	--	--	--	--	--	--	--	--	--	--
Zn	--	--	--	--	--	--	--	--	--	--
C1	321	781	280	1040	5	5	--	--	33	45
SO ₄	305	501	297	691	650	1260	367	602	4021	2700

Parameter	Lime Process, Western Coal Column 140 (400 B)		Lime Process, Western Coal Column 13 (400 B)		Double Alkali Process, Western Coal Column 30 (1000 B)		Double Alkali Process, Western Coal Column 137 (1000 B)	
	Avg.	Highest	Avg.	Highest	Avg.	Highest	Avg.	Highest
Vol (L)	3.00	6.5	3.12	6.5	2.94	11.5	3.10	6.5
pH	11.3	12.1	11.2	12.2	10.9	13.0	12.0	14.0
Ca	19.9	62.0	16.3	20.0	202	570	174	500
Cl	--	--	--	--	--	--	--	--
Cr	--	--	--	--	--	--	--	--
Cu	--	--	--	--	--	0.4	--	0.2
Hg	--	--	--	--	0.15	0.20	0.10	0.20
Mn	--	--	--	--	--	--	--	--
Pb	--	--	--	--	--	--	--	--
Zn	--	--	--	--	--	--	--	--
C1	402	1500	440	1050	487	1040	1360	3100
SO ₄	580	1000	593	925	6000	15000	7500	21000

NOTE: -- = below detection limits or no data; all in mg/l except volume and pH.

TABLE A-6. AVERAGE AND HIGHEST CONCENTRATIONS OF SELECTED CONSTITUENTS FROM SOME-PRIORITY COLUMNS CONTAINING SLUDGES TREATED BY PROCESS E.

Parameter	Line Process, Eastern Coal Column 116 (1000 E)			Limestone Process, Eastern Coal Column 13 (400 E)			Double Alkali Process, Eastern Coal Column 12 (500 E)			Double Alkali Process, Eastern Coal Column 127 (500 E)		
	Avg.	Highest	Lowest	Avg.	Highest	Lowest	Avg.	Highest	Lowest	Avg.	Highest	Lowest
NaCl (g)	2.62	6.5	3.09	6.5	3.39	6.5	2.35	6.5	2.63	6.5	2.69	6.5
pH	11.5	12.5	11.8	12.5	11.3	12.5	11.3	12.5	10.3	12.5	9.8	11.5
Ca	253	679	295	683	681	917	687	971	85.6	290	71.6	101
Si	..	..	0.30	0.30	..	..	..	..	..	..	..	..
Co	..	..	..	..	..	..	..	..	..	..	..	..
Co	..	..	..	..	..	..	..	..	..	..	..	..
Na	0.10	0.10	0.15	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Na	..	..	..	..	..	..	..	..	..	..	..	..
Fe	..	..	1.5	1.5	1.0	1.5	..	..	..	..	..	1.2
Na	..	..	..	..	..	..	..	..	..	..	..	..
Cl	62	83	62	83	75	117	20	73	13	25	26	28
Na ₂	60	106	56	200	662	1560	726	1629	372	823	297	862

Parameter	Line Process, Western Coal Column 100 (1000 E)			Double Alkali Process, Western Coal, Column 52 (1000 E)		
	Avg.	Highest	Lowest	Avg.	Highest	Lowest
NaCl (g)	2.26	6.5	2.20	2.21	6.5	2.21
pH	11.9	12.0	11.5	11.7	12.5	11.7
Ca	103	200	227	529	600	600
Si	0.16	0.20	0.10	..	1.00	..
Co	..	..	..	..	1.5	..
Co	..	..	..	..	1.9	..
Na	0.20	0.20	0.25	0.60	0.20	0.20
Na	..	..	0.2	..	..	..
Fe	..	1.1	..	..	1.0	..
Na	..	..	..	..	..	..
Cl	139	685	175	13	20	..
Na ₂	1260	6000	9750	1050	6700	..

NOTE: .. = below detection limits or no data; all in mg/l except volume and pH.

a Only one column data available for this sludge treated by Process E.

TABLE A-3. AVERAGE AND HIGHEST CONCENTRATIONS OF SELECTED CONSTITUENTS FROM NON-PRIORITY COLLUMS CONTAINING SLUDGES TREATED BY PROCESS V.

Parameter	Lime Process, Eastern Coal		Lime Process, Western Coal			
	Column 54		Column 55			
	Avg. (100 F)	Highest	Avg. (100 F)	Highest		
Vol. (L)	2.31	6.5	2.80	6.5	2.29	6.5
pH	8.7	9.9	9.9	9.9	8.7	10.5
Ca	512	600	666	650	816	6860
Co	---	---	---	---	---	---
Cu	---	---	---	---	---	---
Fe	---	---	---	---	---	---
Mg	9.50	1.00	0.50	0.50	0.60	0.80
Mn	---	---	---	---	---	---
Pb	1.6	1.8	---	---	---	---
Zn	---	---	---	---	---	---
Cl	124	680	106	255	224	765
SO ₄	1600	1600	990	1550	958	1700

NOTE: -- = below detection limits of our tests; all in mg/l except volume and pH.

coal (600) is, as was the priority column, atypically acidic (averaging near pH 6), supporting the possibility of a high contamination of the sludge sample. This sludge also shows high magnesium and manganese leachate concentrations.

The highest levels of heavy metals in the leachate from the untreated sludge columns are just distinguishable above the detection limits. Levels of cadmium over 0.05 mg/l are found in three individual samples of leachates from three of the sludges (400, 500, and 600), chromium at levels greater than 0.5 mg/l in leachate from sludges 500 and 600, copper at levels above 0.2 mg/l from all columns except 600, manganese above 0.1 mg/l in leachates from both lime process sludges (100 and 600), and lead at greater than 1 mg/l in at least one sample from one column with each of the double alkali sludges (500 and 1000). Of the constituents, only zinc was not found at levels over detection limits in any of the leachate samples from any non-priority sludge column.

The data for average and highest individual concentrations of selected constituents are given for all treated-sludge, non-priority columns by process in Tables A-2 through A-6. No major variations in flow patterns, pH values or concentrations for those constituents present in the leachates at detectable levels are seen. The overall leaching patterns are quite similar to those presented and discussed for the priority columns in the body of this report.

Table A-7 compares the average values for the four major constituents from the two non-priority columns with the respective values for their untreated controls as the T/U ratio in a manner similar to that calculated and discussed for the priority columns. (T/U ratio is the average concentration in the leachate from the two treated sludge columns divided by the concentration of the constituent in the leachates from the two control columns containing the same untreated sludge.) Also included are the median T/U ratios for all sludges treated by each process and the median T/U ratios for all processes by sludge type. None of the solidification processes were more than moderately successful in containing the major constituents when evaluated using the procedures employed in this study. For calcium, the median leachate concentration varied from 67 percent in the untreated control leachate for process B, to 93 percent for process G. Magnesium levels were reduced effectively by only two processes, E and F, to 4 percent and 8.5 percent of control levels, respectively. Process G produced leachate which had 2.5 to 330 times as much magnesium as the comparable control values, again indicating a probable addition of large amounts of magnesium in the solidification reagents themselves. Chloride concentrations in the leachate from treated sludge columns were lowered to about 10 percent of that in comparable controls by both processes A and E, and to 25 percent-37 percent by processes F and B. Process G had no net effect on the rate of chloride loss when all sludges are considered, its a median leachate chloride concentration being the same as that of the untreated controls. Sulfate concentrations, likewise, were only moderately reduced by sludge solidification. Sulfate was lowered 21 percent by process E to 70 percent by process A. Process G treated sludges again produced more sulfate in the leachate from treated sludges than from similar, but untreated, control columns.

Table A-7 (bottom) compares the different sludge types as to their

TABLE A-7. T/U RATIOS FOR NON-PRIORITY FGC SLUDGE COLUMNS

Constituent	Lime Process Eastern Coal (100)		Limestone Process Eastern Coal (400)		Double Alkali Process Eastern Coal (500)		Lime Process Western Coal (600)		Double Alkali Process Western Coal (1000)		Median By Process Overall Highest	
	Overall	Highest	Overall	Highest	Overall	Highest	Overall	Highest	Overall	Highest	Overall	Highest
Process A												
Ca	0.86	1.2	0.89	1.1	0.18	0.33	0.70	0.62	0.68	0.58	0.70	0.33
Mg	2.2	0.63	3.6	2.6	0.039	0.89	0.05	0.013	0.78	0.92	0.78	0.89
Cl	0.09	0.11	0.24	0.13	0.097	0.093	0.019	0.009	0.004	0.003	0.09	0.093
SO ₄	0.86	0.63	1.1	0.78	0.041	0.076	0.70	0.57	0.16	0.060	0.70	0.57
Process B												
Ca	0.05	0.13	0.67	1.55	3.4	7.7	0.03	0.05	5.0	1.4	0.67	1.4
Mg	0.05	0.01	2.7	3.9	0.015	0.11	--	--	0.15	0.08	0.83	0.10
Cl	0.62	0.84	0.13	0.05	0.030	0.029	0.70	0.54	0.37	0.74	0.37	0.54
SO ₄	0.23	0.21	0.26	0.47	0.13	0.54	0.31	0.35	0.72	0.48	0.26	0.47
Process E												
Ca	0.41	0.40	0.86	1.30	0.76	0.64	0.14	0.25	5.8	1.7	0.76	0.64
Mg	0.04	0.01	0.18	0.12	0.034	0.33	0.003	0.0005	3.6	3.6	0.04	0.12
Cl	0.08	0.08	0.72	1.3	0.12	0.19	0.03	0.009	0.005	0.005	0.08	0.08
SO ₄	0.03	0.08	0.51	0.66	0.21	0.11	0.18	0.29	0.22	0.12	0.21	0.12
Process F												
Ca	0.73	0.57	Did Not Treat		Did Not Treat		0.99	2.8	Did Not Treat		0.86	1.7
Mg	0.17	0.04	This Sludge		This Sludge		0.008	0.002	This Sludge		0.085	0.02
Cl	0.26	0.34					.24	.17			0.25	0.25
SO ₄	0.70	0.62					.44	.50			0.57	0.56
Process G												
Ca	0.92	0.99	.99	1.4	2.0	1.6	0.93	0.90	6.1	2.6	0.93	1.4
Mg	29.	9.9	330.	280.	2.7	720.	2.5	1.5	130.	160.	29.	160.
Cl	2.3	6.9	30.	76.	1.0	2.5	0.97	2.0	0.36	1.5	1.0	2.5
SO ₄	2.4	2.3	3.8	5.0	0.21	0.28	1.3	2.3	0.71	0.35	1.3	2.3
Median By Sludge Type												
Ca	0.73	0.57	0.87	1.3	1.4	1.1	0.70	0.62	5.4	2.0	0.70	1.4
Mg	0.17	0.04	3.1	3.2	0.037	1.0	0.029	0.007	2.2	2.3	0.029	0.007
Cl	0.26	0.34	0.45	1.3	0.11	0.14	0.24	0.009	0.18	0.43	0.24	0.009
SO ₄	0.70	0.62	0.81	0.72	0.17	0.32	0.44	0.50	0.47	0.54	0.44	0.50

NOTE: T/U ratio = concentration in leachate from treated sludge column divided by that from untreated control column. Each figure is average of two columns. Overall is total mg leached/total t leachate from treated and untreated sludge columns. Highest is highest concentration found in any individual leachate sample from treated and untreated sludge columns.

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relative treatability or suitability of solidification as a contaminant containment alternative. The lime process FGC sludges give a fairly consistent pattern, treatment lowering calcium concentrations in the leachate 70-73 percent, magnesium 3-17 percent, chloride 24-26 percent and sulfate 44-70 percent. The limestone process eastern coal follows a similar pattern except for an apparent increase in magnesium loss rates from the treated sludges. Both double alkali process sludges actually lost more calcium after treatment than before, perhaps caused by the lowering of their very high pH values by the solidification reagents.

Although solidification was successful in containing some of the major contaminants from some of the sludges, no solidification process was successful in containing even all of the major constituents from any one sludge type, or of containing any one major constituent in all sludge types solidified. This again is consistent with the results reported for the priority columns in the body of this report.

The same result is seen, but with wider ranges of values, when the highest concentrations of the constituents in any individual leachate sample are compared. The lime and limestone process FGC sludges appear to present about the same problems to solidification processes, but the very high pH values and sulfate (and presumably sodium and a potassium) losses from the double alkali sludges make their treatment a more demanding challenge.

A histogram comparing the T/U ratios for the four major sludge components for the overall median concentrations is given in Figure A-1 and for highest concentration found in Figure A-2. Sludge solidification process E appears to have the best overall containment capability for both measurements, and even it was only moderately successful. Process G gave the least effective containment losing greater amounts of these major sludge components than the untreated control in every case but one.

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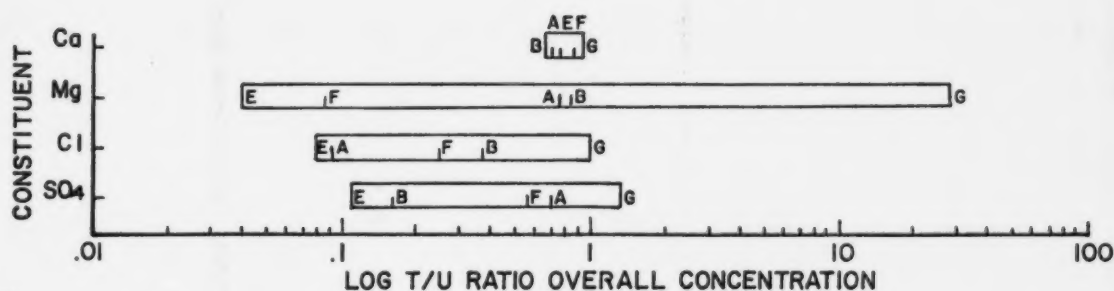


Figure A-1. Plot of the T/U ratio (see text) for four major constituents in the leachate from the non-priority leaching columns. The letters refer to the treatment process.

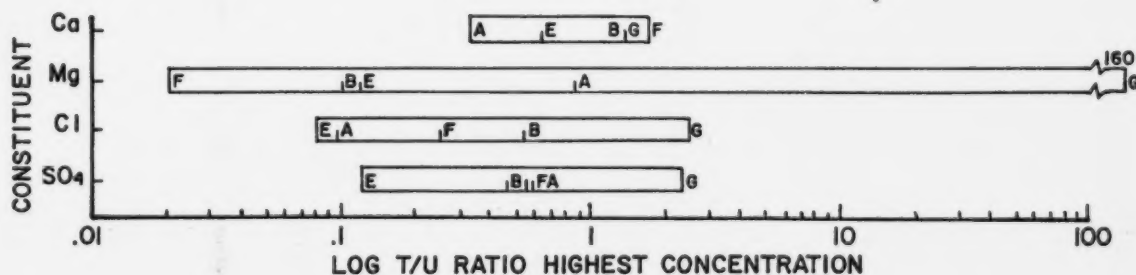


Figure A-2. Plot of the T/U ratio (see text) for four major constituents in the leachate from the non-priority leaching columns. The letters refer to the treatment process.

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APPENDIX B

PRIORITY COLUMN LOADING AND TOTAL AMOUNTS LEACHES

Tables B-1 to B-5 present the actual amount of each sludge constituent in the dry sludge solids which was loaded into each priority column. Materials added in the treatment reagents are not included since the composition and, in some cases, identity, of these additives were not supplied by the processors. Also included is the accumulated mass of each constituent leached from that column over the total leaching period. This is calculated by summing the products of the concentration of each leachate sample in mg/l times the sample volume in liters. These are the figures from which the overall leachate concentrations and percent leached data in Tables 22, 25, 28, 30, and 33 were derived.

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TABLE B-1. AMOUNT OF CONSTITUENTS IN DRY SLUDGE SOLIDS LOADED IN TREATED AND UNTREATED SLUDGE 100 (LIME PROCESS, EASTERN COAL) COLUMNS, AND TOTAL AMOUNT OF EACH CONSTITUENT LEACHED

Constituent	Untreated Sludge Column (40)		Process A. Column (138)		Process B. Column (136)	
	mg in col	Total mg leached	mg in col	Total mg leached	mg in col	Total mg leached
As	277.4	1.289	137.0	1.055	100.3	1.451
Be	89.57	0.192	44.24	0.035	32.37	0.001
Ca	223900	20940	1106000	16000	809400	1746
Cd	546.1	0.019	269.7	0.615	197.4	0.014
Cr	1245	1.091	615.0	0.353	450.0	0.188
Cu	389.9	0.142	192.6	2.290	140.9	0.143
Hg	ND	0.172	ND	0.003	ND	0.014
Hg	26680	69.38	13180	162.1	9641	0.795
Mn	934.3	0.364	461.5	0.028	337.7	0.162
Ni	745.0	1.818	368.0	0.248	269.3	0.442
Pb	98.31	0.054	48.56	0.323	35.53	0.067
Zn	1076	0.276	537.8	0.123	389.1	0.377
Cl	421400	5739	208100	335.5	152300	9130
SO ₄	1545000	45340	763400	24870	538600	13060

	Process E. Column (144)		Process F. Column (81)		Process G. Column	
	mg in col	Total mg leached	mg in col	Total mg leached	mg in col	Total mg leached
As	107.3	0.043	64.99	0.980	34.09	0.586
Be	34.65	0.037	26.98	0.019	11.01	0.195
Ca	865600	6699	524600	16250	275200	18760
Cd	211.3	0.007	127.9	0.049	67.12	0.226
Cr	481.7	0.673	291.7	0.149	153.0	0.626
Cu	150.8	0.521	91.33	0.115	47.91	0.581
Hg	ND	0.003	ND	0.003	ND	2495
Hg	10320	0.845	6249	15.427	3278	2495
Mn	361.5	0.152	218.9	0.051	114.8	1.072
Ni	288.2	0.146	174.5	5.179	91.56	4.892
Pb	38.03	0.060	23.03	0.015	12.08	4.968
Zn	416.5	0.088	252.2	0.282	132.2	0.543
Cl	163000	846.3	98730	2501	51790	24510
SO ₄	597900	533.8	362000	29530	189900	23700

Note: ND = no data.

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TABLE B-2. AMOUNT OF CONSTITUENTS IN DRY SLUDGE SOLIDS LOADED IN TREATED AND UNTREATED SLUDGE 400 (LIMESTONE PROCESS, EASTERN COAL) COLUMNS, AND TOTAL AMOUNT OF EACH CONSTITUENT LEACHED

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Constituent	Untreated Sludge Column (28)		Process A. Column (42)		Process B. Column* (25)	
	mg in col	Total mg leached	mg in col	Total mg leached	mg in col	Total mg leached
As	100.3	0.150	54.10	0.831	34.65	0.076
Be	48.50	0.297	26.18	0.019	16.76	0.016
Ca	2021000	21690	1090000	12510	698500	0.026
Cd	381.2	0.047	205.7	1.892	131.7	0.026
Cr	832.0	0.082	449.0	0.625	287.5	0.074
Cu	429.8	0.560	231.9	0.271	148.6	0.105
Hg	ND	0.033	ND	0.002	ND	0.000
Mg	31200	44.13	16830	110.7	10780	0.047
Mn	558.2	0.148	301.2	2.313	192.9	0.229
Ni	610.1	5.684	329.3	0.256	210.9	1.661
Pb	51.96	0.049	28.04	0.148	17.96	0.004
Se	ND	0.255	ND	0.146	ND	ND
Zn	832.0	0.498	449.0	0.244	557.9	0.901
Cl	138600	707	74830	123.60	287.6	24.72
Cn	ND	0.324	ND	0.256	ND	0.025
NO ₃	ND	0.930	ND	ND	ND	10.33
NO ₂	ND	0.214	ND	ND	ND	0.171
SO ₄	2669000	57460	1440000	30100	922600	9204
SO ₃	ND	25.32	ND	26.16	ND	54.60

Process E. Column (21)		Process G. Column (48)	
mg in col	Total mg leached	mg in col	Total mg leached

As	28.40	0.074	10.81	0.504
Be	13.74	0.001	5.228	0.188
Ca	572500	20100	217800	16390
Cd	108	0.008	41.09	0.199
Cr	235.7	0.609	89.68	0.506
Cu	121.7	0.195	46.34	0.264
Hg	ND	0.004	ND	0.073
Mg	8839	1.676	3363	7079
Mn	158.1	2.914	60.16	2.725
Ni	172.8	0.630	65.77	3.155
Pb	14.72	0.057	5.60	3.253
Se	ND	0.029	ND	0.550
Zn	235.7	0.094	89.68	0.319
Cl	39280	224.3	14940	22912
Cn	ND	0.985	ND	0.212
NO ₃	ND	279	ND	ND
NO ₂	ND	665.5	ND	ND
SO ₄	762500	13390	287700	127874
SO ₃	ND	557.8	ND	152.3

* Sample disintegrated and new column set up on day 154; these data are from new column.

Note: ND = no data.

BOTTOM OF
IMAGE AREA
USING
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

TABLE B-3. AMOUNT OF CONSTITUENTS IN DRY SLUDGE SOLIDS LOADED IN TREATED AND UNTREATED SLUDGE 500 (DOUBLE ALKALE, EASTERN COAL) COLUMNS, AND TOTAL AMOUNT OF EACH CONSTITUENT LEACHED

Constituent	Untreated Sludge Column (35)		Process A. Column (29)		Process B. Column (142)	
	mg in col	Total mg leached	mg in col	Total mg leached	mg in col	Total mg leached
As	327.0	2.101	067.5	12.725	145.6	0.056
Be	51.10	0.007	26.17	0.059	22.75	0.003
Ca	1986000	1839	1017000	1668	884400	21777
Cd	528.1	0.129	270.4	1.994	235.1	0.020
Cr	834.7	2.700	427.5	0.658	371.6	0.433
Cu	364.5	0.694	186.7	2.078	162.3	0.120
Hg	ND	1.180	ND	0.004	ND	0.009
Hg	31240	2.496	15990	19.66	13910	1.239
Mn	1009	0.411	516.5	0.254	449.0	0.063
Ni	599.7	4.060	307.1	1.309	266.9	3.121
Pb	187.4	3.051	95.94	1.575	83.42	0.180
Se	ND	1.510	ND	0.550	ND	0.010
Zn	ND	0.738	753.7	0.155	655.3	0.208
Cl	442900	85.54	226800	1882	197200	1205
SO4	1737000	186080	88900	31100	773600	150600

	Process E. Column (120)		Process G. Column (76)	
	mg in col	Total mg leached	mg in col	Total mg leached
As	133.9	0.038	17.21	2.114
Be	20.94	0.003	2.690	0.102
Ca	813700	6183	104500	16640
Cd	216.3	0.008	27.79	0.150
Cr	341.9	1.593	43.93	0.288
Cu	149.3	4.170	19.19	0.551
Hg	ND	0.007	ND	0.07
Hg	12790	13.33	1644	4180
Mn	413.2	0.034	53080	0.76
Ni	245.6	0.856	31.56	3.1777
Pb	76.75	5.408	9.861	10.65
Se	ND	0.045	ND	0.352
Zn	602.9	1.818	72.47	0.250
Cl	181400	2348	23310	28420
SO4	711800	34300	91450	150000

Note: ND = no data.

TABLE B-4. AMOUNT OF CONSTITUENTS IN DRY SLUDGE SOLIDS LOADED IN TREATED AND UNTREATED SLUDGE 600 (DOUBLE ALKALI, EASTERN COAL) COLUMNS, AND TOTAL AMOUNT OF EACH CONSTITUENT LEACHED

Constituent	Untreated Sludge Column (46)		Process A. Column (56)		Process B. Column (128)	
	mg in col	Total mg leached	mg in col	Total mg leached	mg in col	Total mg leached
As	144.1	0.081	92.21	0.321	37.37	0.760
Be	79.59	0.746	50.94	0.024	20.64	0.002
Ca	917600	19510	587200	13670	237900	434.7
Cd	564.9	0.348	361.6	0.728	146.5	0.019
Cr	857.7	2.845	548.9	0.732	222.4	0.216
Cu	409.5	0.559	262.1	0.438	106.2	0.387
Hg	ND	1.115	ND	0.001	ND	0.008
Mg	39050	1062	24990	86.94	10120	1.800
Mn	1380	79.21	883.3	3.581	357.9	0.184
Ni	519.5	8.635	332.5	0.753	134.7	0.392
Pb	291.9	1.321	186.8	1.938	75.72	0.076
Se	ND	11.665	ND	0.399	ND	0.118
Zn	985.9	1.599	630.9	0.300	554.9	0.587
Cl	227500	13360	145400	225.5	128000	20350
SO ₄	860200	60780	548400	24490	222200	23790

	Process E. Column (90)		Process G. Column (10)	
	mg in col	Total mg leached	mg in col	Total mg leached
As	74.10	0.082	NDL	0.734
Be	41.49	0.112	2.604	0.029
Ca	478300	1818	11900	15352
Cd	294.5	0.010	23.83	0.163
Cr	447.1	0.353	37.66	0.274
Cu	213.5	0.087	6.608	0.529
Hg	ND	0.001	ND	0.052
Mg	20350	10.59	800.9	2552
Mn	719.5	0.094	24.64	1.141
Ni	270.8	0.994	20.43	5.514
Pb	152.2	6.707	17.83	0.018
Se	ND	0.033	ND	ND
Zn	513.9	9.980	23.44	0.301
Cl	118600	82.75	8013	18070
SO ₄	446700	4524	228500	154500

Note: ND = no data.

TABLE B-5. AMOUNT OF CONSTITUENTS IN DRY SLUDGE SOLIDS LOADED IN TREATED AND UNTREATED SLUDGE 1000 (DOUBLE ALKALI, EASTERN COAL) COLUMNS, AND TOTAL AMOUNT OF EACH CONSTITUENT LEACHED

Constituent	Untreated Sludge Column (114)		Process A. Column (115)		Process B. Column (105)	
	mg in col	Total mg leached	mg in col	Total mg leached	mg in col	Total mg leached
As	NDL	1.225	NDL	0.695	NDL	0.135
Ba	34.25	0.230	17.44	0.034	18.45	0.002
Ca	1536000	3984	782500	3187	827900	4281
Cd	313.5	0.999	159.7	1.704	168.9	0.097
Cr	495.4	0.268	252.3	0.934	266.9	1.992
Cu	86.94	0.393	44.27	2.622	46.84	0.600
Hg	ND	1.108	ND	0.002	ND	0.030
Mg	10530	23.380	5365	17.603	5676	7.873
Mn	324.1	0.231	185.1	4.739	174.6	0.665
Ni	268.8	2.937	136.9	1.111	144.8	1.405
Pb	234.5	2.293	119.4	3.031	125.4	3.352
Se	ND	1.162	ND	0.475	ND	0.021
Zn	368.3	0.130	156.9	1.504	166.1	0.355
Cl	105400	17031	53670	171.6	56780	9484
SO ₄	2951000	143730	1582000	32311	1590000	151198

Constituent	Process E. Column (89)		Process G. Column (10)		Process G. Column (17)	
	mg in col	Total mg leached	mg in col	Total mg leached	mg in col	Total mg leached
As	NDL	0.035	57.07	0.272	13.70	0.360
Se	8.911	0.002	31.53	0.036	7.568	0.223
Ca	399800	4907	363500	11095	87260	17850
Cd	81.57	0.006	223.8	0.033	53.73	0.206
Cr	128.9	2.227	339.7	1.215	81.56	0.514
Cu	22.61	0.161	162.2	1.291	38.94	0.176
Hg	ND	0.002	ND	0.003	ND	0.022
Mg	2741	1.053	15470	8.534	3714	5236
Mn	84.32	0.016	546.7	0.137	131.3	3.563
Ni	69.92	0.165	205.8	4.352	49.40	5.068
Pb	61.01	0.072	115.6	1.968	27.76	1.586
Se	ND	ND	ND	ND	ND	0.182
Zn	80.20	0.234	390.5	0.232	93.75	0.589
Cl	27420	81.49	90120	2792	21630	21400
SO ₄	767800	20780	35940	20360	81490	88530

Note: ND = no data.

APPENDIX C

DATA SET FOR PRIORITY LEACHING COLUMNS

Tables C-1 through C-40 give the actual concentrations of all constituents analyzed in each leachate sample collected. Volumes, pH, and conductivities are also included. The data have been blank corrected and are presented in order of column number. The majority of the data presentations discussed in this report are taken from the first 12 sampling periods only (first year), but the data for the second year's leaching (sequence numbers 13-16) are included in this table when available.

COLUMN NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SAMPLE TIME SEC	10.	21.	28.	35.	50.	70.	90.	120.	161.	223.	280.	377.	40.	40.	40.	40.
INLET (DAYS)	1.0000	2.0000	1.0000	1.7730	1.0181	2.2031	2.1007	1.0702	1.7305	3.2355	2.5127	4.5000	NO	NO	NO	NO
PH	10.0	9.0	10.0	8.5	8.0	9.1	9.0	9.2	8.2	8.4	8.5	8.0	NO	NO	NO	NO
SLURRY (mg-OS/cm)	3100.	2100.	2000.	1000.	1070.	1000.	1000.	1550.	1500.	2000.	1010.	2000.	NO	NO	NO	NO
AS (ppm)	0.003	0.040	NO	0.010	0.003	0.005	0.004	0.002	0.000	0.000	0.000	0.010	NO	NO	NO	NO
MG (ppm)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	0.0000	NO	NO	NO	NO
CA (ppm)	0.000	200.1	0.000	120.3	0.000	500.0	310.2	100.1	0.000	0.000	0.000	0.000	NO	NO	NO	NO
CO (ppm)	0.000	0.000	NO	NO	NO	NO	NO	0.000	NO	NO	NO	0.250	NO	NO	NO	NO
CU (ppm)	0.000	0.000	NO	NO	NO	NO	NO	0.000	NO	NO	NO	0.000	NO	NO	NO	NO
FE (ppm)	0.000	0.000	NO	NO	NO	NO	NO	0.000	NO	NO	NO	0.000	NO	NO	NO	NO
NI (ppm)	0.000	NO	NO	NO	NO	NO	NO	0.000	NO	NO	NO	0.000	NO	NO	NO	NO
NO (ppm)	0.000	NO	NO	NO	NO	NO	NO	0.000	NO	NO	NO	0.000	NO	NO	NO	NO
PO (ppm)	0.000	NO	NO	NO	NO	NO	NO	0.000	NO	NO	NO	0.000	NO	NO	NO	NO
SE (ppm)	0.000	NO	NO	NO	NO	NO	NO	0.000	NO	NO	NO	0.000	NO	NO	NO	NO
SI (ppm)	0.000	NO	NO	NO	NO	NO	NO	0.000	NO	NO	NO	0.000	NO	NO	NO	NO
SO (ppm)	0.000	NO	NO	NO	NO	NO	NO	0.000	NO	NO	NO	0.000	NO	NO	NO	NO
TE (ppm)	0.000	NO	NO	NO	NO	NO	NO	0.000	NO	NO	NO	0.000	NO	NO	NO	NO
TI (ppm)	0.000	NO	NO	NO	NO	NO	NO	0.000	NO	NO	NO	0.000	NO	NO	NO	NO
TO (ppm)	0.000	NO	NO	NO	NO	NO	NO	0.000	NO	NO	NO	0.000	NO	NO	NO	NO
TR (ppm)	0.000	NO	NO	NO	NO	NO	NO	0.000	NO	NO	NO	0.000	NO	NO	NO	NO
VO (ppm)	0.000	NO	NO	NO	NO	NO	NO	0.000	NO	NO	NO	0.000	NO	NO	NO	NO
W (ppm)	0.000	NO	NO	NO	NO	NO	NO	0.000	NO	NO	NO	0.000	NO	NO	NO	NO
Y (ppm)	0.000	NO	NO	NO	NO	NO	NO	0.000	NO	NO	NO	0.000	NO	NO	NO	NO
Z (ppm)	0.000	NO	NO	NO	NO	NO	NO	0.000	NO	NO	NO	0.000	NO	NO	NO	NO

NO = NOT DETERMINED.
ND = BELOW DETECTION LIMIT.

Column no.		1		2		3		4		5		6		7		8		9		10		11		12		13		14		15		16		17		18		19		20		21		22		23		24		25		26		27		28		29		30		31		32		33		34		35		36		37		38		39		40		41		42		43		44		45		46		47		48		49		50		51		52		53		54		55		56		57		58		59		60		61		62		63		64		65		66		67		68		69		70		71		72		73		74		75		76		77		78		79		80		81		82		83		84		85		86		87		88		89		90		91		92		93		94		95		96		97		98		99		100		101		102		103		104		105		106		107		108		109		110		111		112		113		114		115		116		117		118		119		120		121		122		123		124		125		126		127		128		129		130		131		132		133		134		135		136		137		138		139		140		141		142		143		144		145		146		147		148		149		150		151		152		153		154		155		156		157		158		159		160		161		162		163		164		165		166		167		168		169		170		171		172		173		174		175		176		177		178		179		180		181		182		183		184		185		186		187		188		189		190		191		192		193		194		195		196		197		198		199		200		201		202		203		204		205		206		207		208		209		210		211		212		213		214		215		216		217		218		219		220		221		222		223		224		225		226		227		228		229		230		231		232		233		234		235		236		237		238		239		240		241		242		243		244		245		246		247		248		249		250		251		252		253		254		255		256		257		258		259		260		261		262		263		264		265		266		267		268		269		270		271		272		273		274		275		276		277		278		279		280		281		282		283		284		285		286		287		288		289		290		291		292		293		294		295		296		297		298		299		300		301		302		303		304		305		306		307		308		309		310		311		312		313		314		315		316		317		318		319		320		321		322		323		324		325		326		327		328		329		330		331		332		333		334		335		336		337		338		339		340		341		342		343		344		345		346		347		348		349		350		351		352		353		354		355		356		357		358		359		360		361		362		363		364		365		366		367		368		369		370		371		372		373		374		375		376		377		378		379		380		381		382		383		384		385		386		387		388		389		390		391		392		393		394		395		396		397		398		399		400		401		402		403		404		405		406		407		408		409		410		411		412		413		414		415		416		417		418		419		420		421		422		423		424		425		426		427		428		429		430		431		432		433		434		435		436		437		438		439		440		441		442		443		444		445		446		447		448		449		450		451		452		453		454		455		456		457		458		459		460		461		462		463		464		465		466		467		468		469		470		471		472		473		474		475		476		477		478		479		480		481		482		483		484		485		486		487		488		489		490		491		492		493		494		495		496		497		498		499		500	
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COLUMN NO.	SAMPLE TIME SEQ NUM	VOL (LITERS)	PH	SLUDGE		PROCESS G										Mg (PPM)	Mn (PPM)
				COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	CO (PPM)	CR (PPM)	CU (PPM)	MG (PPM)	MB (PPM)	MD (PPM)	ME (PPM)	MF (PPM)		
1.	14.	2.1170	8.3	11800.	0.017	0.0796	1090.0	BUL	0.093	BUL	0.0035	227.0	0.080	0.0035	0.0035	0.0035	0.0035
2.	21.	2.1687	6.7	7500.	0.021	0.0020	769.2	0.	0.007	0.050	0.0026	115.5	BUL	0.0026	0.0026	0.0026	0.0026
3.	28.	2.1687	7.0	6300.	0.027	0.0010	519.5	0.	0.006	BUL	0.0012	127.5	0.027	0.0012	0.0012	0.0012	0.0012
4.	35.	1.6934	7.1	6400.	0.017	BUL	795.3	0.0198	0.003	0.003	0.0071	182.5	0.009	0.0071	0.0071	0.0071	0.0071
5.	56.	2.1170	6.8	5800.	0.012	BUL	520.0	0.0005	BUL	0.006	0.0021	160.0	0.030	0.0021	0.0021	0.0021	0.0021
6.	70.	2.7536	7.2	6000.	0.016	0.0020	438.9	BUL	0.006	0.007	0.0160	58.4	0.085	0.0160	0.0160	0.0160	0.0160
7.	105.	3.2353	4.5	5890.	0.005	BUL	249.2	BUL	0.035	0.050	BUL	0.5	BUL	BUL	BUL	0.5	BUL
8.	135.	4.5000	6.8	7100.	0.031	0.0020	589.5	BUL	0.007	0.006	BUL	67.0	0.057	0.006	0.006	0.057	0.057
9.	161.	4.5000	6.8	3280.	0.006	0.0010	580.0	BUL	0.049	BUL	0.0005	44.0	0.025	0.0005	0.0005	0.025	0.025
10.	224.	4.5000	6.8	3200.	0.030	ND	378.3	BUL	ND	ND	ND	27.8	ND	ND	ND	27.8	ND
11.	267.	3.2535	6.5	3800.	0.004	BUL	629.1	BUL	BUL	0.070	0.0005	1.6	BUL	0.0005	0.0005	1.6	BUL
12.	378.	2.2031	6.5	3400.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
13.	451.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	569.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	708.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BOL = BELOW DETECTION LIMITS.

COLUMN NO. 4		SLUDGE 100				PHOSPH. G				TUC				CUD	
SAMPLE SEQ NUM	NI (PPM)	PH (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NH4 (PPM)	N-NH2 (PPM)	SU4 (PPM)	SU3 (PPM)	TUC (PPM)	CUD (PPM)			
1.	0.200	BDL	0.172	0.030	7498.	0.01	ND	ND	6989.	4.	ND	ND			
2.	0.140	0.002	ND	0.020	346.	BDL	ND	ND	4841.	6.	ND	ND			
3.	0.010	BDL	ND	BDL	2021.	ND	ND	ND	5300.	7.	ND	ND			
4.	0.120	0.002	ND	BDL	267.	BDL	ND	ND	4989.	1.	ND	ND			
5.	0.160	BDL	ND	0.020	217.	0.00	ND	ND	3950.	2.	ND	ND			
6.	0.012	1.800	ND	0.012	454.	BDL	ND	ND	3900.	1.	ND	ND			
7.	0.315	BDL	ND	BDL	158.	0.00	ND	ND	3600.	40.	ND	ND			
8.	0.420	BDL	ND	BDL	128.	0.00	ND	ND	4191.	3.	ND	ND			
9.	0.017	BDL	ND	0.003	ND	ND	ND	ND	ND	ND	ND	ND			
10.	ND	BDL	ND	ND	BDL	BDL	ND	ND	2300.	ND	ND	ND			
11.	0.159	BDL	0.007	BDL	BDL	ND	ND	ND	2391.	BDL	ND	ND			
12.	ND	ND	ND	ND	BDL	ND	ND	ND	2450.	BDL	ND	ND			
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND			
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND			
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND			
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ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

ND = NOT DETERMINED.
BOL = BELOW DETECTION LIMITS.

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COLUMN NO. 10		SLUDGE 1000				PROCESS C				S03 (PPM)	T0C (PPM)	C0D (PPM)
SAMPLE SEQ NUM	NI (PPM)	P8 (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-N03 (PPM)	N-N02 (PPM)	S04 (PPM)			
1.	0.140	BDL	0.224	BDL	6598.	0.00	ND	ND	16739.	65.	ND	ND
2.	0.200	ND	ND	BDL	281.	BDL	ND	ND	10591.	6.	ND	ND
3.	0.160	BDL	ND	BDL	1635.	0.00	ND	ND	7400.	6.	ND	ND
4.	0.130	0.003	ND	0.010	195.	BDL	ND	ND	5989.	1.	ND	ND
5.	0.022	BDL	ND	0.010	160.	0.01	ND	ND	4800.	5.	ND	ND
6.	0.008	BDL	ND	0.006	159.	BDL	ND	ND	5400.	ND	ND	ND
7.	0.068	BDL	ND	BDL	113.	0.01	ND	ND	4400.	60.	ND	ND
8.	0.451	BDL	ND	BDL	94.	0.00	ND	ND	4991.	ND	ND	ND
9.	0.017	BDL	ND	0.025	ND	ND	ND	ND	ND	ND	ND	ND
10.	0.499	1.000	ND	BDL	10.	BDL	ND	ND	1400.	2.	ND	ND
11.	BDL	0.003	ND	BDL	40.	ND	ND	ND	1491.	BDL	ND	ND
12.	ND	ND	ND	ND	BDL	ND	ND	ND	2450.	BDL	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
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COLUMN NO.	17	PROCESS G										MG	MG	MN
SAMPLE TIME REQ NUN (DAYS)	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	RE (PPM)	CA (PPM)	LD (PPM)	CR (PPM)	CU (PPM)	MG (PPM)	MG (PPM)	MG (PPM)	MG (PPM)	MN (PPM)
1. 14.	1.8590	8.8	11500.	0.008	0.1198	936.0	BUL	0.083	0.006	0.0068	584.0	0.110		
2. 21.	1.9106	8.5	7400.	0.005	BUL	849.2	BUL	0.004	0.008	0.0003	209.5	0.022		
3. 28.	1.6525	7.2	5800.	0.010	BUL	512.5	0.0100	0.008	0.010	0.0007	196.5	0.061		
4. 35.	2.2891	7.4	5800.	0.005	BUL	739.3	0.0198	0.003	0.020	0.0014	424.3	0.092		
5. 56.	1.9450	7.1	5200.	0.006	BUL	540.0	0.0006	0.002	0.003	0.0023	260.0	0.100		
6. 70.	2.8052	7.7	5200.	0.009	BUL	428.9	BUL	0.003	0.002	ND	104.4	0.086		
7. 105.	3.4074	8.2	4810.	0.013	BUL	459.2	BUL	BUL	0.006	BUL	109.7	0.115		
8. 133.	4.5000	8.1	5600.	0.016	BUL	559.3	BUL	BUL	0.002	BUL	130.0	0.102		
9. 161.	4.5000	8.2	2900.	0.018	BUL	460.0	BUL	0.049	0.	BUL	57.0	0.230		
10. 224.	4.5000	8.0	3100.	0.010	BUL	388.3	0.0003	0.001	BUL	BUL	65.8	0.070		
11. 267.	3.4074	7.9	3200.	0.008	BUL	519.1	0.0011	0.024	ND	BUL	49.9	0.041		
12. 378.	2.2891	7.8	2800.	ND	ND	ND	ND	ND	ND	ND	ND	ND		
13. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		
14. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		
15. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		
16. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		

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COLUMN NO. 17	SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	SLUDGE 600			PROCESS G			S04 (PPM)	T0C (PPM)	C0D (PPM)
					ZN (PPM)	CL (PPM)	CN (PPM)	N=NO3 (PPM)	N=NO2 (PPM)	S04 (PPM)			
	1.	BDL	BDL	0.098	BDL	6998.	0.01	ND	ND	5489.	ND	ND	ND
	2.	BDL	0.001	ND	BDL	469.	BDL	ND	ND	5391.	6.	ND	ND
	3.	0.012	BDL	ND	BDL	2468.	BDL	ND	ND	3700.	6.	ND	ND
	4.	BDL	0.003	ND	0.020	276.	BDL	ND	ND	3389.	2.	ND	ND
	5.	0.012	0.800	ND	0.020	272.	0.01	ND	ND	3150.	1.	ND	ND
	6.	BDL	ND	ND	ND	270.	0.	ND	ND	3300.	ND	ND	ND
	7.	BDL	0.001	ND	BDL	170.	0.01	ND	ND	2460.	70.	ND	ND
	8.	0.532	BDL	ND	BDL	139.	0.00	ND	ND	2991.	ND	ND	ND
	9.	0.040	BDL	ND	0.075	ND	ND	ND	ND	ND	ND	ND	ND
	10.	0.530	1.000	ND	BDL	5.	BDL	ND	ND	1000.	ND	ND	ND
	11.	0.013	0.004	ND	0.008	50.	ND	ND	ND	1691.	BDL	ND	ND
	12.	ND	ND	ND	ND	BDL	ND	ND	ND	2550.	BDL	ND	ND
	13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

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COLUMN NO.	21	PROCESS E										MG	MG	MN
SAMPLE TIME REQ NUM	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	CU (PPM)	CR (PPM)	CU (PPM)	MG (PPM)	MG (PPM)	MN (PPM)	MG (PPM)	MN (PPM)
1. 14.	2.4095	11.4	9000.	HDL	HDL	750.0	HDL	0.181	0.010	0.0003	BUL	0.015	BUL	0.015
2. 21.	1.5149	11.6	9600.	HDL	HDL	977.2	HDL	0.050	0.002	0.0005	HDL	HDL	HDL	HDL
3. 28.	2.7192	12.0	7600.	0.001	HDL	782.5	HDL	0.006	0.006	0.0006	HDL	0.000	HDL	0.000
4. 35.	1.6869	11.9	8100.	0.002	HDL	909.3	HDL	0.002	0.011	0.0005	BUL	HDL	BUL	HDL
5. 49.	2.3407	10.0	5100.	HDL	HDL	635.0	HDL	0.004	0.004	BUL	HDL	HDL	HDL	HDL
6. 63.	1.5149	11.0	8000.	HDL	0.0004	618.9	HDL	0.002	0.012	BUL	HDL	0.004	HDL	0.004
7. 91.	1.6869	12.7	1100.	HDL	HDL	95.2	HDL	0.003	0.022	BUL	HDL	0.007	HDL	0.007
8. 126.	2.2031	11.7	6400.	HDL	HDL	0.5	HDL	0.001	0.008	HDL	HDL	HDL	HDL	HDL
9. 154.	1.6897	6.4	5700.	0.003	HDL	42.0	HDL	0.005	0.002	BUL	HDL	0.003	HDL	0.003
10. 217.	3.1493	11.6	5900.	0.005	HDL	5.0	0.0007	0.001	HDL	BUL	HDL	HDL	HDL	HDL
11. 287.	0.9967	9.3	1820.	0.009	HDL	2.1	0.0005	0.008	0.016	BUL	HDL	HDL	HDL	HDL
12. 378.	3.1493	11.6	2700.	0.012	HDL	131.0	ND	0.005	BUL	BUL	BUL	0.2	0.2	0.2
13. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
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COLUMN NO.		21	SLUDGE 400				PROCESS E						TUC	LUD
SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SU4 (PPM)	SU3 (PPM)	(PPM)	(PPM)	(PPM)	
1.	0.050	0.005	ND	0.002	5.	ND	2.50	184.80	1839.	14.	ND	ND	ND	
2.	0.048	0.006	ND	BDL	BDL	ND	111.00	60.00	186.	15.	ND	ND	ND	
3.	BDL	BDL	ND	BDL	5.	0.01	19.40	29.90	1180.	17.	ND	ND	ND	
4.	0.054	0.003	ND	0.002	10.	0.00	29.80	28.00	1114.	55.	ND	ND	ND	
5.	0.019	0.005	ND	0.007	5.	0.02	ND	BDL	725.	ND	ND	ND	ND	
6.	0.030	0.005	0.019	BDL	BDL	0.01	BDL	BDL	675.	45.	ND	ND	ND	
7.	0.015	BDL	ND	0.006	BDL	0.01	ND	ND	BDL	45.	ND	ND	ND	
8.	0.015	BDL	ND	BDL	ND	0.10	ND	ND	ND	ND	ND	ND	ND	
9.	0.025	0.001	ND	BDL	83.	0.10	ND	ND	52.	29.	ND	ND	ND	
10.	BDL	BDL	ND	BDL	BDL	0.13	ND	ND	85.	36.	ND	ND	ND	
11.	0.008	0.004	ND	0.022	ND	ND	ND	ND	ND	ND	ND	ND	ND	
12.	0.039	BDL	ND	ND	10.	0.01	ND	ND	140.	5.	ND	ND	ND	
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
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16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	

ND = NOT DETERMINED.
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COLUMN NO.	25	PROCESS B										MG (PPM)	MG (PPM)	MN (PPM)
		SAMPLE TIME SEQ NUM	(DAYS)	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	CO (PPM)	CR (PPM)	CU (PPM)	MG (PPM)	
1.	10.	1.6590	12.1	25000.	ND	0.0010	70.0	ND	70.0	ND	0.023	0.020	ND	0.005
2.	20.	1.8590	12.4	17000.	ND	0.0010	729.2	ND	729.2	ND	0.046	0.067	ND	ND
3.	35.	1.6009	12.4	17000.	ND	0.0010	780.5	ND	780.5	ND	0.005	0.040	ND	ND
4.	42.	1.6009	12.0	14000.	ND	0.0033	940.3	ND	940.3	0.1178	0.090	0.045	ND	3.392
5.	63.	1.6009	12.1	12000.	ND	0.005	1000.0	ND	1000.0	ND	0.004	0.029	0.0032	0.002
6.	77.	2.5816	8.0	10500.	ND	0.0041	1236.9	ND	1236.9	ND	0.018	0.038	ND	0.450
7.	119.	3.0477	10.1	12600.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
12.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
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COLUMN NO.	25	SLUDGE				PROCESS B				803	804	805	806	807
		PB	SE	Zn	CL	CN	N-NO3	N-NO2	(PPM)					
SAMPLE NO.	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)
1.	0.179	0.056	0.099	80L	10.	NO	80L	0.10	4089.	7.	NO	NO	NO	NO
2.	0.136	0.040	NO	80L	30.	NO	0.24	0.20	80L	700.	NO	NO	NO	NO
3.	0.118	0.015	0.123	80L	5.	NO	80L	0.03	2800.	65.	NO	NO	NO	NO
4.	0.117	0.009	0.026	80L	102.	NO	80L	0.12	NO	1.	NO	NO	NO	NO
5.	0.011	0.005	NO	80L	20.	0.01	0.04	0.00	5700.	1430.	NO	NO	NO	NO
6.	0.114	0.010	NO	0.017	80L	0.01	80L	0.06	1550.	85.	NO	NO	NO	NO
7.	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
8.	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
9.	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
10.	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
11.	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
12.	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
13.	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
14.	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
15.	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
16.	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

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COLUMN NO.	20	SLUDGE				PROCESS				803	10C	C00
		Wt	Wt	Wt	Wt	Wt	Wt	Wt	Wt			
SAMPLE NO.	Wt	Wt	Wt	Wt	Wt	Wt	Wt	Wt	Wt	Wt	Wt	Wt
1.	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
2.	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
3.	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
4.	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
5.	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
6.	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
7.	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
8.	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
9.	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
10.	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
11.	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
12.	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
13.	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
14.	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
15.	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
16.	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002

NO. 0 NOT DETERMINED.
NO. 0 BELOW DETECTION LIMIT.

SECTION 10
MADE 1000
10000
100000
1000000
10000000
100000000

SAMPLE TIME SEC	20	CO ₂ ppm	70	90	PM	CO ₂ ppm	500	PERCENTS												mg	mg	mg	mg	mg
								CO ₂	AB	BA	CA	CD	ED	FD	GD	HD	ID	JD	KD					
1.	10	1.0000	12.2	2000.	1.700	80%	99.0	80%	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000					
2.	21.	1.0000	11.1	1450.	0.000	0.000	37.0	0.1510	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000					
3.	26.	2.0001	11.0	10000.	0.750	0.000	29.5	80%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000					
4.	35.	2.1170	11.5	8400.	0.700	80%	51.0	0.1030	80%	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000					
5.	56.	2.1007	7.9	6500.	0.500	80%	89.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000					
6.	77.	2.1002	7.9	5700.	0.000	80%	29.9	80%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000					
7.	133.	1.7720	9.0	5100.	0.400	80%	3.2	80%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000					
8.	161.	2.0073	9.5	4300.	0.300	0.000	0.2	80%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000					
9.	180.	3.0033	10.5	4400.	0.320	80%	11.0	80%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000					
10.	250.	0.5000	10.5	2200.	0.020	0.000	120.3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000					
11.	320.	3.3210	8.0	1200.	0.015	80%	00.1	0.000	80%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000					
12.	302.	0.5000	10.3	430.	0.000	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%					
13.	000.	0.5000	9.0	1500.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
14.	500.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
15.	700.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
16.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

NO. OF DEFENSES.
PL. OF DEFENSE LIST.

COLUMN NO. 29		PROCESS A									
NO.	NO.	PG	SG	Zn	EL	Ca	NO-NO3	NO-NO2	NO3	NO2	CO2
(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
17	0.250	0.012	0.003	0.003	0.0	0.02	0.0	0.0	0.0	0.0	0.0
27	0.112	0.000	0.000	0.0	0.0	0.12	0.0	0.0	0.0	0.0	0.0
37	0.100	0.0	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.0	0.0
47	0.0	0.0	0.0	0.0	0.0	0.03	0.0	0.0	0.0	0.0	0.0
57	0.010	0.000	0.0	0.0	0.0	0.04	0.0	0.0	0.0	0.0	0.0
67	0.010	0.013	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.0	0.0
77	0.001	0.001	0.0	0.000	0.071	0.01	0.0	0.0	0.0	0.0	0.0
87	0.000	0.000	0.0	0.0	0.001	0.01	0.0	0.0	0.0	0.0	0.0
97	0.012	0.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
107	0.000	0.002	0.0	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
117	0.007	0.127	0.011	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
127	0.001	0.001	0.007	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
147	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
157	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
167	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

NO = 0.007 0.0000000000
 NO2 = 0.000 0.0000000000

COLUMN NO.		IS	SLUDGE			PROCESS R							
SAMPLE TIME SEQ NUM	(DAYS)	VOL (LITERS)	PH	COND (MMHUS/CM)	AS (PPM)	RE (PPM)	CA (PPM)	CD (PPM)	CR (PPM)	CU (PPM)	MG (PPM)	MS (PPM)	MM (PPM)
1.	1.	0.6030	12.9	62000.	ND	0.0023	620.0	NDL	1.199	0.070	ND	0.0	NDL
2.	8.	0.6955	12.9	56000.	0.025	0.0005	499.2	ND	1.499	ND	0.0002	NDL	0.062
3.	14.	0.4826	12.8	50000.	1.000	0.0060	498.5	ND	0.010	0.299	ND	ND	0.005
4.	21.	0.4482	12.7	56000.	0.100	0.0007	569.3	0.0326	ND	ND	ND	ND	0.001
5.	28.	0.3966	13.1	49000.	0.006	ND	390.0	0.0140	ND	ND	ND	ND	0.016
6.	39.	0.3106	12.5	7000.	0.090	ND	298.9	NDL	0.003	ND	ND	ND	0.017
7.	63.	0.3106	12.6	46000.	ND	ND	ND	ND	ND	ND	ND	ND	ND
8.	91.	1.2912	12.8	46000.	0.012	ND	173.7	ND	0.005	0.154	ND	ND	0.027
9.	120.	0.5686	12.4	50000.	ND	ND	ND	ND	ND	ND	ND	ND	ND
10.	189.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11.	245.	3.4246	12.4	42000.	0.036	ND	0.	0.0152	0.060	ND	ND	0.6	0.050
12.	351.	1.8590	12.6	47800.	0.667	0.0010	NDL	0.0139	0.217	ND	ND	NDL	ND
13.	451.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	569.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	706.	1.8590	9.0	29000.	0.073	NDL	12.6	0.0045	0.002	0.156	NDL	NDL	0.017
16.	814.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
NDL = BELOW DETECTION LIMITS.

COLUMN NO.	35	PROCESS R										TOC (PPM)	COU (PPM)
		SE (PPM)	PH (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SO3 (PPM)	SO4 (PPM)	SO5 (PPM)		
1.	NDL	0.210	ND	NDL	ND	ND	1.30	1.60	55.	ND	ND	ND	ND
2.	2.400	0.999	ND	0.550	22.	ND	1.60	1.70	55.	33991.	ND	ND	ND
3.	ND	0.468	ND	0.040	ND	ND	1.10	1.60	54.	27900.	ND	ND	ND
4.	ND	0.399	0.065	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
5.	ND	0.200	0.690	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6.	ND	0.167	ND	0.020	ND	ND	ND	ND	ND	ND	ND	ND	ND
7.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8.	0.013	0.293	ND	ND	NDL	0.07	ND	ND	575.	3591.	ND	ND	ND
9.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11.	0.530	ND	ND	0.	NDL	0.07	ND	ND	235.	29491.	ND	ND	ND
12.	0.028	ND	ND	0.068	25.	ND	ND	ND	202.	3380.	ND	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	0.010	0.003	0.646	NDL	NDL	ND	ND	ND	220.	16250.	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
NDL = BELOW DETECTION LIMITS.

COLUMN NO.	40	SAMPLE TIME SEQ NUM	VOL (LITERS)	PH	SLUDGE COND (MMHUS/CM)	100 AS (PPM)	PROCESS H						MG (PPM)	MN (PPM)
							BE (PPM)	CA (PPM)	LD (PPM)	CR (PPM)	CU (PPM)	HG (PPM)		
1.	1.	0.1213	8.9	ND	ND	0.0798	700.0	BDL	0.199	0.280	ND	ND	41.0	1.420
2.	8.	0.3450	8.5	3990.	0.050	ND	1221.1	BDL	ND	0.004	0.0003	0.0003	1.7	0.122
3.	14.	2.4439	9.1	5100.	0.036	ND	632.5	BDL	ND	ND	ND	ND	0.9	BDL
4.	21.	3.1493	9.3	4500.	0.070	0.0040	949.3	0.0002	0.002	0.005	0.0013	0.0013	1.0	0.001
5.	28.	1.6009	8.8	4150.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6.	39.	4.5000	9.3	30.	0.030	ND	578.9	ND	ND	0.0012	0.9	0.	0.	0.
7.	63.	3.8031	9.1	1950.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8.	91.	3.5450	6.0	2590.	0.027	ND	133.3	ND	0.044	0.002	0.0017	0.0	ND	ND
9.	126.	2.3751	7.2	3000.	0.022	ND	850.0	BDL	BDL	0.0200	1.0	0.002	1.0	0.002
10.	169.	4.5000	7.8	1800.	0.060	ND	716.3	0.0002	0.003	BDL	BDL	ND	3.8	ND
11.	245.	2.6504	7.5	2300.	0.013	ND	589.1	0.0004	0.001	0.002	ND	ND	3.9	ND
12.	353.	2.3751	9.1	2040.	0.112	0.0050	651.0	BDL	ND	BDL	BDL	BDL	2.0	ND
13.	451.	2.2891	8.2	2100.	BDL	BDL	657.0	0.0015	0.052	BDL	BDL	BDL	0.8	BDL
14.	569.	1.3428	6.7	2000.	0.007	0.1120	598.6	BDL	0.001	BDL	BDL	0.	0.5	0.010
15.	708.	4.5000	8.4	1300.	0.013	BDL	210.3	BDL	BDL	0.0222	BDL	0.0222	0.4	0.
16.	814.	4.5000	7.8	1200.	BDL	BDL	224.8	BDL	0.006	BDL	BDL	BDL	0.3	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

INFORM GUIDE SHEET

TOP OF
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COLUMN NO.	40	SLUDGE				100				PROCESS R				TUC				CUD			
		NI (PPM)	PH (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NH ₃ (PPM)	N-NH ₂ (PPM)	SU4 (PPM)	SU3 (PPM)	TUC (PPM)	CUD (PPM)	SU4 (PPM)	SU3 (PPM)	TUC (PPM)	CUD (PPM)	SU4 (PPM)	SU3 (PPM)	TUC (PPM)	CUD (PPM)
1.	0.500	0.110	ND	0.920	ND	815.	ND	1.90	6.05	1184.	BDL	ND	ND	1184.	BDL	ND	ND	1184.	BDL	ND	ND
2.	ND	0.006	ND	ND	ND	815.	ND	3.20	5.70	1161.	BDL	BDL	47.	1161.	BDL	BDL	47.	1161.	BDL	BDL	47.
3.	0.001	0.004	0.023	ND	963.	963.	0.10	2.90	5.50	1175.	BDL	BDL	18.	1175.	BDL	BDL	18.	1175.	BDL	BDL	18.
4.	ND	ND	0.012	ND	916.	916.	0.09	8.00	4.85	1089.	BDL	40.	BDL	1089.	BDL	40.	BDL	1089.	BDL	40.	BDL
5.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6.	ND	ND	ND	ND	0.	5.	0.	ND	ND	1500.	ND	3.	ND	1500.	ND	3.	ND	1500.	ND	3.	ND
7.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8.	0.006	ND	ND	ND	ND	BDL	BDL	ND	ND	1691.	ND	ND	ND	1691.	ND	ND	ND	1691.	ND	ND	ND
9.	0.010	0.006	ND	BDL	BDL	ND	BDL	ND	ND	1542.	ND	ND	ND	1542.	ND	ND	ND	1542.	ND	ND	ND
10.	ND	ND	ND	ND	ND	36.	BDL	ND	ND	1550.	3.	ND	ND	1550.	3.	ND	ND	1550.	3.	ND	ND
11.	ND	ND	ND	ND	ND	BDL	BDL	ND	ND	2391.	BDL	ND	ND	2391.	BDL	ND	ND	2391.	BDL	ND	ND
12.	0.015	0.003	ND	BDL	ND	ND	ND	ND	ND	1495.	BDL	ND	ND	1495.	BDL	ND	ND	1495.	BDL	ND	ND
13.	0.019	BDL	ND	BDL	BDL	BDL	BDL	ND	ND	1393.	5.	ND	ND	1393.	5.	ND	ND	1393.	5.	ND	ND
14.	1.070	BDL	0.004	0.	BDL	BDL	BDL	ND	ND	174.	ND	ND	ND	174.	ND	ND	ND	174.	ND	ND	ND
15.	BDL	BDL	0.011	BDL	BDL	BDL	BDL	ND	ND	250.	ND	ND	ND	250.	ND	ND	ND	250.	ND	ND	ND
16.	BDL	ND	0.017	BDL	BDL	BDL	BDL	ND	ND	547.	ND	ND	ND	547.	ND	ND	ND	547.	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

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TYPING GUIDE SHEET

TOP OF
IMAGE
AREA

IMPROVED
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COLUMN NO.	42	SAMPLE TIME SEQ NUM	VOL (LITERS)	PH	SLUDGE		400	PROCESS A							MN (PPM)
					COND	(MMHOS/CM)		AS	BE	CA	LD	CR	CU	HG	HG
1.	14.	1,6009	9.4	9.4	5000.		0.029	BDL	BDL	783.0	BDL	BDL	0.013	BDL	BDL
2.	21.	1,5149	9.0	9.0	400.		0.040	BDL	BDL	601.2	0.1060	BDL	BDL	0.0003	8.4
3.	26.	1,9450	7.8	7.8	2400.		0.023	0.0030	BDL	390.5	BDL	0.030	ND	BDL	6.7
4.	35.	2,0310	8.8	8.8	2600.		0.036	BDL	BDL	120.3	0.0738	0.001	0.043	BDL	4.0
5.	56.	2,0654	8.4	8.4	2400.		0.075	BDL	BDL	470.0	0.0004	0.005	0.004	0.0004	5.1
6.	77.	1,8418	7.6	7.6	2200.		0.040	BDL	BDL	624.9	BDL	0.003	BDL	BDL	4.6
7.	133.	1,8590	7.9	7.9	2100.		0.055	BDL	BDL	479.2	BDL	BDL	BDL	BDL	8.1
8.	161.	3,2353	7.0	7.0	2400.		0.020	0.0040	BDL	209.3	BDL	0.045	BDL	BDL	4.2
9.	196.	2,6912	8.2	8.2	2400.		ND	ND	ND	ND	ND	ND	ND	ND	3.8
10.	259.	3,3558	7.0	7.0	2000.		0.011	BDL	BDL	448.3	0.0010	0.111	BDL	BDL	1.7
11.	329.	3,4074	7.3	7.3	2100.		0.015	BDL	BDL	619.1	0.4400	BDL	0.006	0.0002	ND
12.	392.	4,5000	8.6	8.6	1800.		0.027	BDL	BDL	430.0	0.0045	0.002	BDL	BDL	2.1
13.	ND	ND	ND	ND	ND.		ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

BOTTOM OF
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Typing Guide Sheet

TOP OF
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DRIVER'S
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COLUMN NO. 42		SLUDGE			PROCESS A				CUD (PPM)		
SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N=NO3 (PPM)	N=NO2 (PPM)	S04 (PPM)	S03 (PPM)	TUC (PPM)
1.	0.036	0.009	0.037	0.002	ND	0.06	ND	ND	ND	ND	ND
2.	BDL	ND	0.029	BDL	ND	0.04	ND	ND	ND	1.	ND
3.	BDL	0.000	ND	BDL	ND	ND	ND	ND	ND	1.	ND
4.	BDL	BDL	ND	BDL	ND	0.	ND	ND	ND	1.	ND
5.	0.010	ND	ND	BDL	21.	0.01	ND	ND	1900.	1.	ND
6.	BDL	0.009	ND	0.	12.	0.01	ND	ND	1725.	8.	ND
7.	BDL	BDL	ND	0.011	BDL	0.01	ND	ND	1600.	BDL	ND
8.	0.024	0.034	ND	BDL	BDL	0.00	ND	ND	1241.	1.	ND
9.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10.	0.024	BDL	ND	0.002	BDL	BDL	ND	ND	1450.	ND	ND
11.	BDL	BDL	0.006	BDL	BDL	ND	ND	ND	1591.	BDL	ND
12.	BDL	BDL	0.005	BDL	5.	ND	ND	ND	1260.	BDL	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

BOTTOM OF
IMAGE AREA
DRIVER'S
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Typing Guide Sheet

TOP OF
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AREA

DROPPED
HEAD
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COLUMN NO.		46	PROCESS R										MN
SAMPLE TIME SEC NUM	(DAYS)	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	HE (PPM)	CA (PPM)	LD (PPM)	CR (PPM)	CU (PPM)	HG (PPM)	HG (PPM)	MN (PPM)
1.	1.	0.1385	ND	ND	ND	0.0078	736.0	0.	0.999	0.090	ND	310.0	3.160
2.	8.	2.4955	4.9	9500.	ND	ND	699.2	0.0200	0.999	0.048	0.0026	289.5	3.122
3.	14.	3.8031	3.7	9200.	0.002	0.0160	749.5	0.0200	ND	0.089	ND	2.5	2.795
4.	21.	1.6009	3.8	8600.	ND	0.0300	629.3	0.0198	ND	0.012	ND	69.3	0.692
5.	28.	3.3214	4.4	3400.	ND	ND	ND	ND	ND	ND	ND	ND	ND
6.	39.	4.5000	6.8	20.	ND	0.0090	578.9	8UL	ND	ND	ND	3.4	0.014
7.	63.	2.6848	6.9	1910.	ND	0.0031	618.2	8UL	ND	0.004	0.0007	3.0	0.040
8.	91.	4.5000	6.2	1880.	ND	ND	126.6	8UL	0.031	0.002	8UL	5.5	ND
9.	126.	0.1385	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10.	189.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11.	245.	4.5000	7.6	1740.	ND	ND	549.1	0.0004	0.001	0.002	ND	12.9	15.000
12.	353.	3.4074	7.0	2100.	0.004	0.1420	601.0	8UL	ND	8UL	ND	8.4	0.058
13.	451.	1.6869	7.8	2100.	8UL	8UL	567.0	0.0010	0.038	8UL	8UL	9.9	0.028
14.	569.	2.1170	7.0	2100.	0.006	0.0430	579.6	8UL	8UL	8UL	0.0006	7.0	0.006
15.	708.	2.2031	7.3	2000.	8UL	8UL	543.3	8UL	8UL	8UL	8UL	0.3	0.005
16.	814.	1.5149	7.3	2000.	8UL	8UL	572.8	8UL	0.001	8UL	8UL	0.5	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

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COLUMN NO. 46		SLUDGE 600			PROCESS 4			SUA		SUS		TUC		CUD	
SAMPLE SEQ NUM	NI (PPM)	PH (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N=NO3 (PPM)	N=NO2 (PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)
1.	0.300	0.056	ND	0.210	ND	0.01	5.90	BDL	2789.	0.	7.	92.			
2.	0.900	0.039	ND	ND	2173.	ND	9.30	ND	2941.	0.	5.	20.			
3.	0.116	0.025	2.900	0.290	1874.	0.09	7.40	ND	2550.	0.	BDL	58.			
4.	0.024	ND	0.108	0.100	427.	BDL	1.50	ND	2114.	BDL	BDL	12.			
5.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND			
6.	ND	ND	ND	0.	10.	0.01	ND	ND	1475.	1.	3.	ND			
7.	ND	ND	ND	ND	15.	BDL	ND	ND	1500.	1.	ND	ND			
8.	0.011	BDL	ND	ND	BDL	0.01	0.01	ND	1241.	2.	ND	ND			
9.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND			
10.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND			
11.	ND	ND	ND	BDL	BDL	ND	ND	ND	1441.	0.	ND	ND			
12.	1.289	ND	ND	0.031	ND	ND	ND	ND	1460.	BDL	ND	ND			
13.	0.009	BDL	ND	BDL	BDL	ND	ND	ND	1743.	3.	ND	ND			
14.	0.523	0.	0.040	BDL	BDL	ND	ND	ND	1944.	3.	ND	ND			
15.	BDL	BDL	0.054	BDL	BDL	ND	ND	ND	1500.	ND	ND	ND			
16.	0.	ND	0.160	BDL	BDL	ND	ND	ND	1447.	ND	ND	ND			

ND = NOT DETERMINED.
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COLUMN NO.	48	PROCESS G										MG	MG	MG
SAMPLE TIME SEQ NUM	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	CD (PPM)	CH (PPM)	CU (PPM)	MG (PPM)	MG (PPM)	MG (PPM)	MG (PPM)	MG (PPM)
1. 14.	2,3751	8.6	16000.	0.011	0.0098	900.0	BUL	0.123	BUL	0.0018	510.0	0.150	0.082	0.115
2. 21.	1,3600	6.7	12400.	0.013	BUL	789.2	0.	0.003	0.006	0.0038	569.5	0.082	0.082	0.115
3. 28.	1,7213	7.2	8400.	0.018	BUL	449.5	0.0100	0.002	0.027	0.0053	375.5	0.115	0.115	0.115
4. 35.	1,2568	7.1	9000.	0.006	BUL	749.3	0.0198	0.003	0.020	0.0036	519.3	0.112	0.112	0.112
5. 56.	2,6332	6.6	8400.	0.012	BUL	490.0	0.0006	BUL	0.020	0.0024	510.0	0.120	0.120	0.120
6. 70.	2,7020	7.6	8000.	0.008	BUL	468.9	BUL	0.003	0.008	0.0140	169.4	0.129	0.129	0.129
7. 105.	3,1493	7.6	7240.	0.013	BUL	429.2	BUL	BUL	0.023	0.0015	129.7	0.090	0.090	0.090
8. 133.	4,1816	7.2	8200.	0.044	BUL	509.3	BUL	BUL	0.002	BUL	180.0	0.087	0.087	0.087
9. 161.	2,8052	7.7	4600.	0.008	0.0060	540.0	BUL	0.045	BUL	0.0004	75.0	0.065	0.065	0.065
10. 224.	4,5000	6.9	4700.	0.018	ND	488.3	BUL	ND	ND	ND	65.8	ND	ND	ND
11. 287.	3,3214	6.7	5000.	0.012	BUL	509.1	0.0010	0.018	0.005	BUL	94.9	0.075	0.075	0.075
12. 376.	4,5000	6.7	2000.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
13. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BOL = BELOW DETECTION LIMITS.

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COLUMN NO.	46	SLUDGE				PROCESS				S04	S03	T0C	C0D
		NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)				
1.	0.140	NDL	0.233	NDL	NDL	5998.	0.02	ND	ND	8239.	ND	ND	ND
2.	0.200	0.002	ND	NDL	NDL	531.	NDL	ND	ND	6991.	6.	ND	ND
3.	0.120	NDL	ND	0.006	0.006	2343.	0.	ND	ND	6700.	7.	ND	ND
4.	0.160	0.003	ND	ND	0.020	324.	0.	ND	ND	5989.	ND	ND	ND
5.	0.160	NDL	ND	ND	0.010	402.	0.01	ND	ND	5050.	2.	ND	ND
6.	NDL	1.200	ND	ND	NDL	256.	0.01	ND	ND	550.	ND	ND	ND
7.	0.002	NDL	ND	ND	NDL	193.	0.01	ND	ND	4750.	40.	ND	ND
8.	0.388	NDL	ND	ND	NDL	162.	0.01	ND	ND	4891.	ND	ND	ND
9.	0.019	NDL	ND	ND	0.031	ND	ND	ND	ND	ND	ND	ND	ND
10.	ND	NDL	ND	ND	ND	45.	NDL	ND	ND	3000.	ND	ND	ND
11.	NDL	0.001	ND	ND	0.013	50.	ND	ND	ND	2491.	NDL	ND	ND
12.	ND	ND	ND	ND	ND	NDL	ND	ND	ND	1700.	NDL	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
NDL = BELOW DETECTION LIMITS.

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PROCESS A

COLUMN NO.	S ₆	VOL (LITERS)	PH	SLUDGE CONC (MG/ML)	AS (PPM)	RE (PPM)	CA (PPM)	LD (PPM)	CR (PPM)	CU (PPM)	MG (PPM)	MG (PPM)	MN (PPM)
SAMPLE TIME													
SEQ NUM	(DAYS)												
1.	14.	1,400	9.5	5000.	0.010	NDL	751.0	NDL	0.004	0.022	NDL	5.0	NDL
2.	21.	2,203	9.4	300.	0.006	0.0005	505.2	0.1710	0.009	0.015	NDL	3.2	1.522
3.	26.	2,269	9.1	2200.	0.009	0.0030	244.5	NDL	0.000	NDL	NDL	2.5	NDL
4.	35.	1,659	9.1	2400.	0.007	NDL	109.3	0.1400	NDL	0.004	NDL	3.9	NDL
5.	56.	2,506	7.9	1950.	0.004	NDL	490.0	0.0024	0.008	0.005	0.0002	2.2	0.002
6.	77.	1,755	7.6	2000.	0.006	NDL	546.9	NDL	0.003	NDL	NDL	4.6	NDL
7.	133.	1,650	8.3	2020.	0.006	NDL	419.2	NDL	NDL	0.003	NDL	2.2	NDL
8.	161.	2,973	7.4	2400.	0.004	0.0050	319.3	NDL	0.043	0.005	NDL	2.5	NDL
9.	196.	2,805	8.5	2390.	0.006	0.0030	760.0	NDL	0.010	0.030	NDL	2.6	NDL
10.	259.	4,500	7.4	1200.	0.007	NDL	248.3	0.0003	0.023	NDL	NDL	0.7	NDL
11.	329.	3,253	7.5	1600.	0.004	NDL	349.1	0.0006	NDL	0.004	0.0005	1.4	0.016
12.	392.	4,500	7.9	2100.	0.035	NDL	509.0	NDL	NDL	NDL	NDL	1.6	NDL
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

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COLUMN NO. 56		SLUDGE 600				PROCESS A						
SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SiO4 (PPM)	SU4 (PPM)	1UC (PPM)	CUD (PPM)
1.	0.034	0.009	0.092	BDL	ND	0.06	ND	ND	ND	ND	ND	ND
2.	0.029	0.005	0.077	BDL	ND	0.04	ND	ND	ND	ND	ND	ND
3.	0.200	ND	ND	BDL	ND	BDL	ND	ND	ND	ND	ND	ND
4.	BDL	BDL	ND	BDL	ND	BDL	ND	ND	ND	ND	ND	ND
5.	BDL	0.800	ND	BDL	42.	0.01	ND	ND	1400.	1.	ND	ND
6.	BDL	BDL	ND	BDL	13.	BDL	ND	ND	1450.	7.	ND	ND
7.	BDL	0.005	ND	0.008	BDL	0.01	ND	ND	1500.	0.	ND	ND
8.	0.014	0.016	ND	0.	8.	0.00	ND	ND	1441.	1.	ND	ND
9.	0.009	0.002	ND	0.014	ND	ND	ND	ND	ND	ND	ND	ND
10.	0.010	BDL	ND	0.006	BDL	BDL	ND	ND	550.	2.	ND	ND
11.	BDL	BDL	0.013	BDL	BDL	ND	ND	ND	841.	BDL	ND	ND
12.	0.002	BDL	0.009	BDL	5.	ND	ND	ND	1340.	BDL	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

RETURN OF
IMAGE AREA
FOR TAD-25
AND TAD-26
TAD-27

Typing Guide Sheet

Column No.	Sample Time Seq Num	Days	Vol (Liters)	pH	Sludge Conc (mg/ml)	Nutrients					Cu (ppm)	Mn (ppm)	Fe (ppm)	Zn (ppm)	Cd (ppm)
						Ca	LB	CR	CU	Mn					
1.	14.	1.000	1.000	9.0	1000.	0.120	0.0010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.	21.	2.100	2.100	7.5	11500.	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3.	28.	1.7730	1.7730	7.5	9000.	0.140	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4.	35.	1.4117	1.4117	7.2	9000.	0.030	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5.	50.	1.0590	1.0590	7.0	7400.	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6.	70.	3.2181	3.2181	7.7	7400.	0.030	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7.	105.	3.4074	3.4074	7.9	6000.	0.070	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8.	135.	4.5000	4.5000	7.6	4000.	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9.	161.	2.7192	2.7192	8.0	5500.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10.	224.	4.5000	4.5000	7.7	5400.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11.	267.	3.4074	3.4074	7.4	5200.	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12.	378.	2.3751	2.3751	7.4	3100.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BOL = BELOW DETECTION LIMITS.

COLUMN NO.	SAMPLE TIME REQ NUM	DAYS	VUL (LITERS)	PH	SLUDGE		PROCESS F					Cu (PPM)	Hg (PPM)	Hg (PPM)	Mn (PPM)
					CUND (MMHUS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	LD (PPM)	CH (PPM)	CO (PPM)				
1.	14.		2,1170	9.8	3400.	0.037	BDL	698.0	BDL	BDL	0.006	0.0004	0.7	0.003	
2.	21.		2,1687	9.6	2400.	0.044	BDL	419.2	BDL	BDL	0.006	BDL	BDL	BDL	
3.	26.		2,7708	9.5	1800.	0.016	BDL	399.5	BDL	BDL	0.001	BDL	BDL	BDL	
4.	35.		1,7730	9.1	2300.	0.107	BDL	669.3	0.0003	0.002	0.001	BDL	BDL	BDL	
5.	56.		2,0310	7.9	1990.	0.026	BDL	550.0	0.0003	BDL	0.002	BDL	0.5	0.003	
6.	70.		1,8869	9.7	2400.	0.044	BDL	718.9	BDL	BDL	0.019	0.0004	0.	BDL	
7.	98.		1,8590	9.3	1900.	0.031	0.0100	385.2	BDL	BDL	BDL	0.0004	0.3	BDL	
8.	126.		1,9278	8.2	1900.	0.018	BDL	579.3	BDL	0.004	0.002	BDL	1.1	0.004	
9.	161.		2,0310	8.0	1750.	0.050	BDL	590.0	0.0172	BDL	BDL	BDL	1.1	BDL	
10.	223.		3,493	7.3	2190.	0.032	BDL	448.3	0.0007	BDL	BDL	BDL	BDL	BDL	
11.	286.		2,7880	7.6	2180.	0.039	BDL	649.1	BDL	0.049	0.001	BDL	1.0	BDL	
12.	37.	0004,5000		7.0	230.	0.009	BDL	641.0	BDL	BDL	BDL	BDL	0.1	BDL	
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

COLUMN NO. 81		PROCESS F									
SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	SLUDGE 100			PROCESS F				CUD (PPM)
				ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SO4 (PPM)	SU3 (PPM)	TUC (PPM)
1.	0.024	BDL	ND	0.004	581.	6.03	29.80	145.80	1389.	80.	ND
2.	0.022	ND	ND	BDL	255.	2.73	30.00	90.00	1016.	65.	ND
3.	0.008	BDL	ND	0.010	102.	1.80	40.40	55.90	725.	100.	ND
4.	0.015	0.001	ND	BDL	153.	1.62	11.80	60.00	1139.	550.	ND
5.	0.006	BDL	ND	BDL	ND	1.41	ND	ND	ND	ND	ND
6.	0.008	0.005	ND	0.002	31.	1.21	ND	10.00	120.	14.	ND
7.	0.002	BDL	ND	BDL	ND	0.69	0.04	BDL	ND	9.	ND
8.	BDL	BDL	ND	BDL	6.	0.36	20.00	0.05	1316.	5.	ND
9.	BDL	BDL	ND	0.004	BDL	0.27	ND	ND	1154.	5.	ND
10.	0.094	BDL	ND	0.044	5.	ND	ND	ND	1350.	2.	ND
11.	0.017	BDL	ND	BDL	10.	ND	0.03	0.02	1166.	ND	ND
12.	0.012	BDL	ND	BDL	BDL	ND	ND	ND	1700.	BDL	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

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COLUMN NO.	89	PH	SLUDGE	1000	DE	CA	LD	CM	CU	HG	HG	MU	MN
SAMPLE TIME SEQ NUM	(DAYS)	(LITERS)	(MMHOS/CM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)
1.	14.	2.7536	12.5	14200.	HDL	390.0	HDL	ND	0.008	0.0002	0.0002	HDL	0.002
2.	21.	1.6418	12.4	15700.	HDL	467.2	HDL	0.599	0.016	0.0003	0.0003	HDL	HDL
3.	28.	2.4055	12.5	10300.	HDL	219.5	HDL	0.010	0.001	HDL	HDL	HDL	HDL
4.	35.	2.2375	12.4	13000.	HDL	309.3	HDL	0.200	0.014	0.0003	0.0003	HDL	HDL
5.	49.	2.2719	11.6	10600.	HDL	285.0	HDL	0.070	0.005	HDL	HDL	HDL	0.002
6.	63.	1.6009	12.0	15000.	HDL	123.9	HDL	0.002	HDL	HDL	HDL	ND	HDL
7.	91.	1.6869	12.6	16000.	HDL	5.2	HDL	0.004	0.016	HDL	HDL	HDL	HDL
8.	126.	1.8590	12.1	12000.	HDL	200.3	HDL	0.004	0.002	HDL	HDL	ND	HDL
9.	154.	1.5321	8.0	7400.	HDL	220.0	HDL	HDL	HDL	ND	ND	0.1	HDL
10.	217.	3.0633	11.6	5440.	HDL	23.5	0.0003	0.005	HDL	HDL	HDL	ND	HDL
11.	287.	2.0310	11.9	4290.	0.001	10.1	0.0001	0.011	0.007	HDL	HDL	0.0	HDL
12.	378.	3.2353	9.2	1900.	0.007	0.	HDL	0.145	HDL	HDL	HDL	0.0	HDL
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
HDL = BELOW DETECTION LIMITS.

COLUMN NO.	69	SLUDGE 1000				PROCESS 2				SUS	TUC	CUD
		SAMPLE SEQ NUM	NI (PPM)	PH (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N=NU3 (PPM)	N=NU2 (PPM)	SU4 (PPM)	(PPM)
1.		BDL	BDL	BDL	ND	0.007	BDL	ND	4.00	238.60	5509.	ND
2.		0.026	0.020	0.020	ND	BDL	20.	ND	142.00	95.00	316.	ND
3.		BDL	BDL	BDL	ND	0.009	5.	ND	34.40	59.90	1550.	ND
4.		0.020	BDL	BDL	ND	0.001	BDL	ND	31.40	67.00	1389.	ND
5.		0.011	0.006	0.006	ND	0.006	BDL	ND	ND	32.00	900.	ND
6.		0.010	0.002	BDL	BDL	BDL	BDL	ND	BDL	24.00	745.	ND
7.		0.002	ND	ND	ND	BDL	BDL	ND	ND	ND	BDL	ND
8.		0.005	ND	ND	ND	BDL	ND	ND	ND	ND	ND	ND
9.		BDL	BDL	BDL	ND	BDL	21.	ND	ND	ND	BDL	ND
10.		BDL	BDL	BDL	ND	BDL	BDL	ND	ND	ND	9.	ND
11.		BDL	0.006	0.006	ND	0.014	ND	ND	ND	ND	ND	ND
12.		BDL	ND	ND	ND	0.022	BDL	BDL	ND	ND	BDL	ND
13.		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

COLUMN NO.	Q0	VOL (LITERS)	PH	SLUDGE COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	CD (PPM)	CR (PPM)	CU (PPM)	HG (PPM)	HG (PPM)	MN (PPM)
SAMPLE TIME SEQ NUM (DAYS)													
1. 14.		1.6353	11.3	5000.	BDL	BDL	190.0	BDL	0.022	0.002	0.0007	0.0	0.001
2. 21.		1.8590	12.2	6000.	BDL	BDL	217.1	BDL	0.032	0.012	BDL	BDL	BDL
3. 28.		1.8590	11.7	4200.	ND	ND	ND	ND	ND	ND	ND	ND	ND
4. 35.		1.6009	11.2	3000.	BDL	0.0030	113.3	BDL	0.010	0.002	BDL	BDL	BDL
5. 56.		1.8590	11.2	1300.	BDL	BDL	117.0	0.0005	0.010	0.003	BDL	ND	BDL
6. 77.		1.9276	9.9	2020.	BDL	BDL	112.9	BDL	0.018	0.010	BDL	BDL	BDL
7. 119.		3.0289	9.6	940.	ND	ND	ND	ND	ND	ND	ND	ND	ND
8. 154.		1.9450	11.4	1359.	BDL	BDL	43.3	BDL	0.008	0.007	BDL	0.1	BDL
9. 162.		2.9773	9.7	526.	0.002	0.0010	4.3	BDL	0.017	BDL	BDL	0.1	0.030
10. 210.		3.3730	7.9	410.	BDL	0.0230	35.3	0.0001	0.008	BDL	BDL	ND	BDL
11. 280.		3.4418	8.4	410.	0.010	0.0080	11.1	0.0003	0.015	BDL	BDL	BDL	BDL
12. 329.		3.5794	10.4	920.	0.012	BDL	42.0	ND	0.005	BDL	BDL	BDL	BDL
13. ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14. ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15. ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16. ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

COLUMN NO. 90		SLUDGE 600		PROCESS E			S03		S04		S03		TOC		COD	
SAMPLE SEQ NUM	HI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-N03 (PPM)	N-N02 (PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)
1.	BDL	0.005	0.005	0.001	ND	0.02	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2.	0.003	BDL	ND	5.200	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3.	ND	ND	0.005	ND	26.	0.06	ND	ND	BDL	BDL	16.	ND	ND	ND	ND	ND
4.	0.005	0.001	0.010	0.003	ND	0.04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
5.	BDL	0.002	ND	0.002	ND	0.06	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6.	BDL	BDL	ND	BDL	10.	0.02	ND	ND	16.	16.	12.	ND	ND	ND	ND	ND
7.	ND	ND	ND	ND	5.	0.00	ND	ND	BDL	BDL	40.	ND	ND	ND	ND	ND
8.	BDL	0.001	ND	BDL	BDL	0.09	ND	ND	621.	621.	0.	ND	ND	ND	ND	ND
9.	0.004	0.300	ND	0.034	BDL	ND	ND	ND	842.	842.	ND	ND	ND	ND	ND	ND
10.	0.178	0.800	ND	BDL	BDL	ND	ND	ND	53.	53.	ND	ND	ND	ND	ND	ND
11.	BDL	0.900	ND	0.010	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
12.	0.102	BDL	ND	BDL	BDL	BDL	ND	ND	46.	46.	BDL	BDL	ND	ND	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

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ND = NOT DETERMINED.
BOL = BELOW DETECTION LIMITS.

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COLUMN NO. 105		SLUDGE 1000				PROCESS 8				TOC (PPM)		COD (PPM)	
SAMPLE SEQ NUM	NI (PPM)	PH (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N=NO3 (PPM)	N=NO2 (PPM)	SO4 (PPM)	SO3 (PPM)	TOC (PPM)	COD (PPM)	
1.	0.275	0.375	ND	BDL	1302.	ND	BDL	0.15	20989.	1450.	ND	ND	
2.	0.055	0.499	ND	0.070	764.	ND	0.23	0.21	9891.	1000.	ND	ND	
3.	BDL	BDL	ND	0.009	509.	ND	0.93	BDL	6800.	850.	ND	ND	
4.	0.048	0.049	ND	BDL	5.	ND	0.05	0.60	154.	260.	ND	ND	
5.	ND	ND	ND	ND	BDL	BDL	0.32	0.05	920.	260.	ND	ND	
6.	BDL	0.008	ND	BDL	BDL	BDL	0.02	0.04	4125.	ND	ND	ND	
7.	0.003	0.050	0.014	0.012	ND	0.10	ND	ND	ND	ND	ND	BDL	
8.	BDL	BDL	ND	BDL	27.	ND	ND	ND	BDL	50.	ND	ND	
9.	0.012	BDL	ND	0.002	31.	BDL	ND	ND	BDL	24.	ND	ND	
10.	0.011	BDL	ND	BDL	BDL	BDL	ND	ND	440.	32.	ND	ND	
11.	ND	ND	ND	ND	BDL	ND	ND	ND	BDL	BDL	ND	ND	
12.	0.011	BDL	ND	BDL	BDL	BDL	ND	ND	54.	BDL	ND	ND	
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

ND = NOT DETERMINED.
BOL = BELOW DETECTION LIMITS.

COLUMN NO. 11a		PROCESS W													
SAMPLE TIME SEQ NUM	(DAYS)	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	SE (PPM)	CA (PPM)	CO (PPM)	CM (PPM)	CU (PPM)	MG (PPM)	MN (PPM)			
1.	1.	0.8500	10.9	67000.	ND	0.0188	15.0	1.0300	ND	0.140	ND	0.0	ND	ND	ND
2.	8.	4.5000	12.4	60000.	0.005	0.0018	11.6	ND	ND	0.0004	ND	ND	ND	ND	ND
3.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4.	21.	3.2525	11.4	1490.	ND	0.0001	41.3	0.0001	ND	0.030	ND	ND	ND	ND	ND
5.	28.	3.0977	10.6	330.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6.	34.	3.3241	10.5	340.	ND	ND	74.9	MDL	ND	0.020	ND	MDL	0.	MDL	0.
7.	63.	2.4439	9.9	295.	ND	ND	59.8	ND	ND	ND	ND	MDL	0.002	MDL	0.002
8.	91.	2.5816	7.7	310.	ND	ND	45.5	ND	0.015	0.005	ND	ND	ND	ND	ND
9.	126.	4.0456	9.7	400.	ND	ND	74.0	ND	0.011	MDL	ND	ND	ND	ND	ND
10.	189.	4.5000	8.8	340.	ND	ND	44.3	0.0002	0.010	MDL	ND	0.1	ND	ND	ND
11.	245.	2.6504	7.3	300.	ND	ND	49.1	0.0006	0.016	ND	0.0004	2.1	0.003	2.1	0.003
12.	353.	3.2353	6.1	359.	0.016	0.0390	101.0	0.0016	MDL	MDL	ND	0.1	0.001	0.1	0.001
13.	451.	4.5000	9.0	340.	MDL	MDL	137.0	0.0006	0.016	MDL	MDL	0.0	0.006	0.0	0.006
14.	569.	2.0310	7.3	400.	MDL	0.0330	77.6	0.0003	MDL	MDL	0.	MDL	0.	MDL	0.
15.	708.	4.5000	7.5	450.	MDL	MDL	49.3	MDL	0.001	MDL	MDL	0.6	0.	0.6	0.
16.	814.	4.5000	7.3	480.	MDL	MDL	160.6	0.0007	MDL	MDL	0.	1.4	ND	1.4	ND

ND = NOT DETERMINED.
MDL = BELOW DETECTION LIMITS.

COLUMN NO. 115			SLUDGE 1000			POULISS A										Mg	Mn
SAMPLE TIME SEC	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	LD (PPM)	CM (PPM)	CU (PPM)	Fe (PPM)	Na (PPM)	NO ₃ (PPM)	NO ₂ (PPM)	CO ₂ (PPM)	SO ₄ (PPM)		
1. 10.	1.0500	11.0	2000.	0.110	0.0050	235.0	0.01	0.004	0.070	0.004	0.004	0.004	0.004	0.004	0.0		
2. 21.	1.0600	10.7	1300.	0.035	0.0003	61.1	0.01	0.174	0.070	0.002	0.002	0.002	0.002	0.002	2.722		
3. 26.	2.2031	10.1	8000.	0.035	0.0000	41.5	0.01	0.100	0.070	0.002	0.002	0.002	0.002	0.002	0.0		
4. 35.	2.0052	10.5	5000.	0.020	0.0012	70.1	0.1050	0.008	0.047	0.008	0.008	0.008	0.008	0.008	0.0		
5. 50.	2.3407	9.3	8000.	0.010	0.001	57.0	0.0000	0.015	0.030	0.015	0.015	0.015	0.015	0.015	0.0		
6. 77.	1.7730	7.5	8000.	0.011	0.001	45.9	0.01	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.0		
7. 133.	3.3210	9.0	8000.	0.033	0.001	21.2	0.01	0.001	0.033	0.001	0.001	0.001	0.001	0.001	0.0		
8. 101.	3.0055	8.9	4820.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		
9. 190.	3.1403	9.9	4250.	0.015	0.0010	2.2	0.01	0.011	0.030	0.011	0.011	0.011	0.011	0.011	0.0		
10. 259.	3.4074	10.1	1900.	0.010	ND	558.3	0.0000	0.025	0.01	0.025	0.025	0.025	0.025	0.025	0.002		
11. 320.	4.5000	10.0	2100.	0.003	0.001	25.1	0.01	0.001	0.008	0.001	0.001	0.001	0.001	0.001	0.0		
12. 302.	4.5000	8.0	1800.	0.002	0.001	21.3	0.0001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002		
13. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		
14. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		
15. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		
16. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		

ND = NOT DETERMINED.
NDL = BELOW DETECTION LIMITS.

COLUMN NO. 115		SLUDGE 1000				PROCESS A							
SAMPLE TIME SEC NUM	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	LD (PPM)	CR (PPM)	CU (PPM)	MG (PPM)	MB (PPM)	MA (PPM)	
1. 16.	1.8590	11.6	20000.	0.110	0.0058	235.0	NDL	0.044	0.078	NDL	0.0	NDL	
2. 21.	1.6669	10.7	1100.	0.035	0.0043	81.1	NDL	0.179	0.076	0.0002	0.0	2.722	
3. 26.	2.2031	10.1	6000.	0.035	0.0040	41.5	NDL	0.100	ND	NDL	0.2	NDL	
4. 35.	2.8952	10.5	5000.	0.024	0.0012	76.1	0.1050	0.008	0.047	NDL	1.4	NDL	
5. 56.	2.3407	9.3	4000.	0.018	NDL	57.0	0.0000	0.015	0.030	0.0005	0.0	NDL	
6. 77.	1.7730	7.5	4000.	0.011	NDL	45.4	NDL	0.006	0.018	NDL	NDL	NDL	
7. 133.	3.3214	9.0	4000.	0.033	NDL	21.2	NDL	NDL	0.033	NDL	NDL	NDL	
8. 161.	3.0655	8.9	4020.	ND	ND	ND	ND	ND	ND	ND	ND	ND	
9. 190.	3.1493	9.9	4250.	0.015	0.0010	2.2	NDL	0.011	0.030	NDL	0.0	NDL	
10. 250.	3.4074	10.1	1900.	0.016	NDL	548.3	0.0000	0.025	NDL	NDL	NDL	0.002	
11. 320.	4.5000	10.0	2100.	0.003	NDL	25.1	NDL	NDL	0.008	NDL	0.0	NDL	
12. 392.	4.5000	8.0	1000.	0.002	NDL	21.3	0.0001	NDL	NDL	NDL	0.2	0.002	
13. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
14. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
15. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
16. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	

ND = NOT DETERMINED.
NDL = BELOW DETECTION LIMITS.

COLUMN NO.	120	SLUDGE	500	PROCESS E										MG	MG	MN
SAMPLE TIME	WOL	PH	COND	AS	SE	CA	CO	CR	CU	MG	MG	MG	MG	MG	MG	
(DAYS)	(LITERS)		(COND/CM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	(PPM)	
1. 10.	2.3579	12.0	31000.	MDL	MDL	100.0	MDL	0.145	0.014	0.0003	MDL	MDL	MDL	MDL	MDL	
2. 21.	1.7213	12.0	20500.	MDL	MDL	100.1	MDL	0.100	0.000	MDL	MDL	MDL	MDL	MDL	MDL	
3. 20.	3.2000	12.0	12200.	0.001	MDL	300.5	MDL	0.031	0.001	0.0015	MDL	MDL	MDL	0.005	MDL	
4. 35.	1.0000	12.0	17000.	MDL	MDL	205.3	MDL	0.019	0.002	0.0000	MDL	MDL	MDL	MDL	MDL	
5. 00.	2.0050	11.7	12700.	MDL	MDL	320.0	MDL	0.012	0.002	MDL	MDL	MDL	MDL	MDL	0.001	
6. 03.	1.0000	12.0	21000.	MDL	MDL	123.0	MDL	0.017	MDL	MDL	MDL	MDL	MDL	MDL	MDL	
7. 01.	1.0000	12.5	10000.	0.003	MDL	107.2	MDL	0.000	MDL	MDL	MDL	MDL	MDL	MDL	MDL	
8. 120.	1.0000	12.3	15000.	MDL	MDL	350.3	MDL	0.001	MDL	MDL	MDL	MDL	MDL	MDL	MDL	
9. 150.	1.0010	9.0	10000.	MDL	MDL	300.0	MDL	0.002	MDL	MDL	MDL	MDL	MDL	0.1	MDL	
10. 217.	1.0000	12.0	10050.	MDL	MDL	320.3	MDL	0.000	MDL	MDL	MDL	MDL	MDL	MDL	MDL	
11. 207.	2.0032	12.2	0310.	0.001	0.0010	30.1	0.0001	0.010	0.000	MDL	MDL	MDL	MDL	1.0	MDL	
12. 370.	0.5000	12.0	5000.	0.000	MDL	131.0	MDL	0.012	0.000	MDL	MDL	MDL	MDL	1.5	MDL	
13. 00	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	
14. 00	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	
15. 00	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	
16. 00	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	

MDL = NOT DETERMINED.
MDL = 0.0000 DETECTION LIMITS.

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TABLE 1 (continued)

COL. 100 NO. 120	SAMPLING SITE NO.	PERCENT										SOL	TOL	TOL	TOL
		PH	SE	Zn	CL	Ca	Na+K	Na+K	Na+K	Na+K	Na+K				
	1.	80%	80%	0.005	75%	80%	3.00	402.00	3520.	115.	80%	80%	80%	80%	80%
	2.	0.010	0.011	80%	41.	80%	340.00	450.00	220.	450.	80%	80%	80%	80%	80%
	3.	0.010	80%	80%	10.	0.00	80.00	90.00	4250.	50.	80%	80%	80%	80%	80%
	4.	0.010	0.010	80%	80%	0.00	88.00	71.00	1500.	45.	80%	80%	80%	80%	80%
	5.	80%	0.010	0.007	80%	0.10	80%	80%	800.	100.	80%	80%	80%	80%	80%
	6.	0.011	0.010	0.027	80%	0.01	80%	20.00	850.	75.	80%	80%	80%	80%	80%
	7.	80%	80%	1.000	80%	80%	80%	55.00	80%	75.	80%	80%	80%	80%	80%
	8.	80%	1.000	80%	80%	0.10	0.00	0.02	80%	105.	80%	80%	80%	80%	80%
	9.	80%	0.010	80%	200.	0.07	0.05	0.02	80%	21.	80%	80%	80%	80%	80%
	10.	0.005	80%	80%	80%	0.10	80%	80%	4020.	20.	80%	80%	80%	80%	80%
	11.	0.005	1.100	0.020	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%
	12.	0.000	80%	80%	80%	80%	80%	80%	350.	80%	80%	80%	80%	80%	80%
	13.	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%
	14.	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%
	15.	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%
	16.	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%

80% = 80% of 100%
80% = 80% of 100% 1.1010

COLUMN NO.	136	SAMPLE TIME SEW NUM (DAYS)	VOL (LITERS)	PH	SLUDGE		PROCESS H							Mn (ppm)	Mg (ppm)	Mn (ppm)	Mn (ppm)
					COND (MMHOS/CM)	AS (ppm)	BE (ppm)	CA (ppm)	CU (ppm)	CM (ppm)	LU (ppm)	CU (ppm)	Mg (ppm)				
1.	7.	4,500	12.4	12.4	12400.	0.050	BDL	350.0	0.009	0.001	BDL	0.009	0.0002	0.0	0.029	BDL	BDL
2.	14.	1,850	12.2	12.2	9800.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3.	21.	1,5037	12.4	12.4	7750.	0.060	BDL	17.5	BDL	BDL	BDL	BDL	0.0001	BDL	0.003	BDL	BDL
4.	28.	1,8762	12.0	12.0	6850.	0.070	BDL	15.7	BDL	0.002	BDL	0.014	0.0042	BDL	BDL	BDL	BDL
5.	42.	2,4045	12.2	12.2	5950.	0.100	BDL	19.2	BDL	BDL	BDL	0.007	0.0020	BDL	0.002	BDL	BDL
6.	56.	2,0310	14.0	14.0	4700.	0.034	BDL	12.9	BDL	BDL	BDL	0.005	0.0003	BDL	BDL	BDL	BDL
7.	91.	1,7730	11.7	11.7	3200.	0.070	0.0004	10.2	BDL	BDL	BDL	0.005	BDL	BDL	0.001	BDL	BDL
8.	126.	2,3751	10.8	10.8	2900.	0.036	BDL	14.5	BDL	0.075	BDL	0.009	BDL	BDL	BDL	BDL	BDL
9.	161.	1,9106	8.3	8.3	2400.	0.140	BDL	ND	BDL	BDL	BDL	BDL	BDL	0.1	BDL	BDL	BDL
10.	224.	3,1214	8.5	8.5	2100.	0.064	BDL	4.8	0.0040	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
11.	273.	2,9429	8.6	8.6	2390.	ND	BDL	2.3	0.0002	BDL	BDL	BDL	BDL	0.0	BDL	BDL	BDL
12.	365.	4,5000	10.2	10.2	1800.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
13.	498.	4,5000	8.4	8.4	1400.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	611.	4,5000	9.8	9.8	1400.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	735.	4,5000	7.4	7.4	1500.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

COLUMN NO. 136			SLUDGE 100			PROCESS H					SUS	TDC	COD
SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	S04 (PPM)	SUS (PPM)	TDC (PPM)	COD (PPM)	
1.	0.015	BDL	ND	0.080	781.	ND	HDL	1.80	460.	405.	ND	ND	
2.	ND	ND	ND	ND	611.	ND	4.33	1.00	451.	340.	ND	ND	
3.	0.011	0.005	ND	0.004	489.	ND	HDL	0.42	542.	275.	ND	ND	
4.	0.036	0.009	ND	BDL	408.	ND	0.10	0.41	294.	505.	ND	ND	
5.	0.010	0.006	ND	0.004	362.	0.01	0.01	0.12	525.	475.	ND	ND	
6.	0.115	0.006	ND	BDL	194.	0.02	0.06	0.04	341.	ND	ND	ND	
7.	0.012	0.003	0.005	0.001	ND	ND	ND	ND	ND	ND	ND	ND	
8.	BDL	BDL	ND	BDL	95.	0.00	ND	ND	491.	225.	ND	ND	
9.	BDL	BDL	ND	BDL	718.	0.00	ND	ND	452.	156.	ND	ND	
10.	BDL	0.001	ND	BDL	BDL	0.01	ND	ND	700.	24.	ND	ND	
11.	ND	ND	ND	ND	5.	ND	ND	ND	511.	HDL	ND	ND	
12.	ND	ND	ND	ND	BDL	HDL	ND	ND	360.	HDL	ND	ND	
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

COLUMN NO. 138		PROCESS A									
SAMPLE TIME SED NUM (DAYS)	VOL (LITERS)	PH	COND (MHOS/CM)	AS (PPM)	HE (PPM)	CA (PPM)	LD (PPM)	CM (PPM)	CU (PPM)	MG (PPM)	MN (PPM)
1. 14.	1.6869	9.1	3700.	0.049	BDL	1680.0	BDL	BDL	0.010	BDL	0.002
2. 21.	2.0310	9.2	290.	0.040	BDL	536.2	0.1980	BDL	BDL	BDL	BDL
3. 28.	1.9450	9.4	2200.	0.080	0.0030	504.5	0.	BDL	BDL	0.0002	BDL
4. 35.	1.6869	9.0	2100.	0.054	0.0003	155.2	0.0818	BDL	BDL	0.0002	BDL
5. ND	2.0650	7.0	1850.	0.040	BDL	370.0	0.0007	0.002	0.004	BDL	0.002
6. 77.	1.7730	7.8	1680.	0.020	BDL	518.9	BDL	0.003	BDL	BDL	BDL
7. 133.	1.9450	8.1	1870.	0.050	BDL	439.2	BDL	BDL	0.006	BDL	BDL
8. 161.	3.5794	7.8	2020.	0.048	0.0080	409.3	BDL	0.037	0.488	BDL	BDL
9. 196.	2.4611	8.3	1650.	0.005	BDL	410.0	BDL	0.025	BDL	BDL	BDL
10. 259.	4.5000	8.0	2500.	0.031	BDL	398.5	0.0004	0.035	BDL	BDL	BDL
11. 329.	3.4074	7.3	1400.	0.006	BDL	369.1	0.0005	BDL	0.005	0.0004	0.003
12. 392.	4.5000	8.2	1900.	0.019	BDL	549.0	BDL	BDL	0.046	BDL	BDL
13. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16. ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

COLUMN NO. 136		PROCESS A									
SAMPLE SEQ		SLUDGE					100				
NUM	NI (PPM)	PH (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SU4 (PPM)	SU3 (PPM)	TOL (PPM)
1.	0.030	0.008	0.035	0.003	ND	0.28	ND	ND	ND	ND	ND
2.	0.018	0.003	0.005	BDL	ND	0.09	ND	ND	ND	ND	ND
3.	BDL	BDL	ND	BDL	ND	0.16	ND	ND	ND	ND	ND
4.	BDL	BDL	ND	0.010	ND	ND	ND	ND	ND	ND	ND
5.	BDL	BDL	ND	BDL	51.	0.01	ND	ND	1500.	0.	ND
6.	BDL	BDL	ND	BDL	26.	BDL	ND	ND	1350.	3.	ND
7.	BDL	BDL	ND	0.005	5.	0.00	ND	ND	1500.	0.	ND
8.	0.011	0.022	ND	BDL	3.	0.01	ND	ND	1510.	1.	ND
9.	0.002	0.001	ND	BDL	ND	ND	ND	ND	ND	ND	ND
10.	0.019	BDL	ND	0.003	BDL	BDL	ND	ND	900.	ND	ND
11.	BDL	BDL	0.007	BDL	40.	ND	ND	ND	891.	BDL	ND
12.	BDL	0.048	0.006	BDL	BDL	AD	ND	ND	1110.	BDL	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

COLUMN NO.	142	SAMPLE TIME SEQ NUM (DAYS)	VOL (LITERS)	PH	SLUDGE		500	PROCESS B					MG (PPM)	MG (PPM)	MN (PPM)
					COND (MMHOS/CM)	AS (PPM)		BE (PPM)	CA (PPM)	CU (PPM)	CR (PPM)	LD (PPM)			
1.	7.	3,3730	13.0	45000.	0.004	0.0003	243.0	BDL	0.064	BDL	0.0011	BDL	0.	BDL	0.010
2.	14.	3,2353	12.7	4000.	BDL	BDL	326.2	BDL	0.008	BDL	0.0002	BDL	BDL	BDL	BDL
3.	21.	2,6332	12.5	21200.	BDL	BDL	390.5	BDL	0.002	BDL	0.0004	BDL	BDL	BDL	BDL
4.	28.	4,5000	12.0	6800.	BDL	0.0003	6.0	BDL	0.002	0.010	0.0010	0.0015	0.2	BDL	BDL
5.	42.	1,9278	12.4	13200.	BDL	BDL	504.0	BDL	0.002	0.005	0.0015	BDL	BDL	BDL	BDL
6.	56.	2,0310	12.2	10000.	BDL	BDL	798.9	BDL	0.064	0.002	0.005	BDL	BDL	BDL	0.002
7.	91.	1,6869	11.8	80000.	BDL	BDL	719.2	BDL	0.005	0.005	0.005	BDL	BDL	BDL	BDL
8.	126.	1,8590	12.0	7000.	BDL	BDL	565.3	BDL	0.004	0.005	0.005	BDL	BDL	BDL	BDL
9.	161.	3,4762	11.4	6200.	BDL	BDL	580.0	BDL	0.004	0.005	0.005	BDL	BDL	BDL	BDL
10.	224.	2,5472	11.5	3900.	BDL	BDL	288.3	BDL	0.004	0.005	0.005	BDL	BDL	BDL	BDL
11.	273.	3,7515	10.4	1220.	ND	ND	99.1	BDL	0.010	0.003	0.003	BDL	BDL	BDL	BDL
12.	365.	3,5794	11.2	2600.	0.012	BDL	211.0	BDL	ND	ND	ND	ND	ND	ND	ND
13.	498.	4,5000	11.0	5400.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	611.	4,5000	11.3	5400.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	735.	4,5000	11.0	2000.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

COLUMN NO. 142		PROCESS H										
SAMPLE SEQ NUM	NI (PPM)	PH (PPM)	SE (PPM)	SLUDGE 500		CN (PPM)	N=NO3 (PPM)	N=NO2 (PPM)	S04 (PPM)	S03 (PPM)	T0C (PPM)	C0D (PPM)
				ZN (PPM)	CL (PPM)							
1.	0.373	ND	ND	0.050	5.	ND	BDL	0.60	18489.	215.	ND	ND
2.	0.048	0.004	ND	BDL	BDL	0.02	0.82	0.72	17491.	240.	ND	ND
3.	0.058	0.008	ND	0.002	BDL	ND	BDL	0.13	7000.	80.	ND	ND
4.	0.011	0.009	ND	BDL	153.	ND	BDL	0.09	539.	50.	ND	ND
5.	0.062	0.016	ND	0.006	BDL	0.01	0.06	0.08	4000.	125.	ND	ND
6.	0.015	0.010	ND	BDL	40.	0.	0.01	0.05	8.	ND	ND	ND
7.	0.005	0.008	0.006	ND	ND	0.00	ND	ND	ND	ND	ND	ND
8.	BDL	1.999	ND	BDL	32.	0.00	ND	ND	221.	75.	ND	ND
9.	0.	0.008	ND	BDL	82.	0.00	ND	ND	117.	14.	ND	ND
10.	0.526	BDL	ND	BDL	BDL	ND	ND	ND	130.	9.	ND	ND
11.	ND	ND	ND	ND	5.	BDL	ND	ND	8.	BDL	ND	ND
12.	BDL	BDL	ND	BDL	BDL	BDL	ND	ND	114.	BDL	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

COLUMN NO.	144	SAMPLE TIME SEQ NUM	VOL (LITERS)	PH	SLUDGE		100	PROCESS E				CU	H ₂	H ₂	MN
					COND	(MMPOS/CM)		CA	CD	CR	CD				
		(DAYS)					(PPH)	(PPH)	(PPH)	(PPH)	(PPH)	(PPH)	(PPH)	(PPH)	(PPH)
1.	14.	2.9429	11.8	BDL	6400.	BDL	330.0	BDL	0.054	0.003	BDL	BDL	BDL	BDL	0.008
2.	21.	1.8590	12.2	BDL	6000.	BDL	439.2	BDL	0.054	0.004	0.0007	BDL	BDL	BDL	0.008
3.	28.	3.4418	11.7	BDL	5000.	BDL	505.5	BDL	0.020	0.004	0.0008	BDL	BDL	BDL	0.008
4.	35.	3.3042	11.6	BDL	3200.	BDL	320.3	BDL	0.012	0.002	BDL	BDL	BDL	BDL	0.008
5.	49.	2.2891	10.3	BDL	5000.	BDL	400.0	BDL	0.008	0.007	0.0004	BDL	BDL	BDL	BDL
6.	63.	2.0310	11.3	BDL	2800.	BDL	130.9	BDL	0.004	0.002	BDL	BDL	BDL	BDL	BDL
7.	91.	1.8590	11.9	BDL	6000.	BDL	245.2	BDL	0.010	0.021	BDL	BDL	BDL	BDL	BDL
8.	126.	2.1170	11.3	BDL	4300.	BDL	134.3	BDL	0.008	0.002	BDL	BDL	BDL	BDL	BDL
9.	154.	1.9106	8.3	BDL	2000.	BDL	20.0	BDL	0.009	BDL	BDL	BDL	BDL	BDL	BDL
10.	217.	1.8934	10.1	BDL	1200.	BDL	18.3	BDL	0.004	BDL	BDL	BDL	BDL	BDL	BDL
11.	287.	2.6332	10.3	BDL	1300.	BDL	4.7	BDL	0.0002	0.013	BDL	BDL	BDL	BDL	BDL
12.	378.	3.4074	8.8	BDL	1000.	BDL	BDL	BDL	0.044	0.044	BDL	BDL	BDL	BDL	0.008
13.	451.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	569.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	708.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

COLUMN NO.	144	SLUDGE 100					PROCESS E					S03 (PPM)	S04 (PPM)	S05 (PPM)	S06 (PPM)	S07 (PPM)	S08 (PPM)
		PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-N03 (PPM)	N-N02 (PPM)	S01 (PPM)	S02 (PPM)							
1.		0.008	ND	0.004	50.	ND	ND	5.30	382.80	14.	10.	ND	ND	ND	ND	ND	ND
2.		0.010	ND	BDL	71.	ND	ND	600.00	365.00	5.	15.	ND	ND	ND	ND	ND	ND
3.		BDL	ND	BDL	50.	BDL	BDL	543.40	199.90	BDL	12.	ND	ND	ND	ND	ND	ND
4.		0.	ND	0.003	29.	ND	ND	511.80	112.00	10.	70.	ND	ND	ND	ND	ND	ND
5.		0.008	ND	0.007	20.	BDL	BDL	ND	24.00	9.	ND	ND	ND	ND	ND	ND	ND
6.		0.001	0.910	BDL	BDL	BDL	BDL	BDL	12.00	BDL	55.	ND	ND	ND	ND	ND	ND
7.		BDL	ND	0.008	15.	0.01	ND	ND	ND	BDL	36.	ND	ND	ND	ND	ND	ND
8.		0.006	ND	BDL	AD	0.07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9.		0.004	ND	BDL	125.	ND	ND	ND	ND	3.	13.	ND	ND	ND	ND	ND	ND
10.		BDL	ND	BDL	BDL	0.03	ND	ND	ND	38.	16.	ND	ND	ND	ND	ND	ND
11.		0.003	ND	BDL	AD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
12.		BDL	ND	BDL	BDL	BDL	BDL	ND	ND	74.	BDL	ND	ND	ND	ND	ND	ND
13.		ND	ND	ND	AD	ND	ND	AD	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.		ND	ND	ND	AD	ND	ND	AD	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.		ND	ND	ND	AD	ND	ND	AD	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.		ND	ND	ND	AD	ND	ND	AD	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.